From :

The Right Hon. Lord Riverdale

(Chairman of the Appeals Committee, Royal Air Force Benevolent Fund)

To :

The Purchaser of this Book.

I and my colleagues wish to acknowledge the contribution you have made to the Royal Air Force Benevolent Fund by the purchase of this book, which conveys such wonderfully useful technical information to those who should know about it.

I can assure you that the Royal Air Force Benevolent Fund needs all the help that can be given to it. We have over 22,000 on our books at the present time and, as the raids spread—and with greater magnitude—into the enemy country, our responsibilities increase. We are not only thinking of the immediate present: we have got to think of the future of a lot of young children whose education we shall have to undertake. Last, but not least, when the R.A.F. come back and are demobilised, their education, in many cases, will have to be completed and they will have to be trained for the jobs which must be found for them.

It is fitting that I should also express our appreciation to the Committee responsible for our work and to all responsible for the preparation of this book; the fact that this work has been done gratuitously and with enthusiasm will enable the Fund to benefit more than would otherwise have been possible, and we are grateful for your personal help.

Yours sincerely,

RIVERDALE.

1, Sloane Street,
London, S.W. 1.

Part of fusilage of a wrecked German aeroplane being moved for examination.

A METALLURGICAL STUDY OF GERMAN AND ITALIAN AIRCRAFT ENGINE AND AIRFRAME PARTS

By

THE AERO COMPONENTS SUB-COMMITTEE

of the

TECHNICAL ADVISORY COMMITTEE

to the

SPECIAL AND ALLOY STEELS COMMITTEE

Arranged, in co-operation with the Committee,
by CHARLES A. OTTO, Editor of *METALLURGIA*.

Published by
THE KENNEDY PRESS LTD.,
21, Albion Street, Manchester, 1,
and Bedford Street, London, W.C.2.
1943.

THIS BOOK IS PRODUCED IN COMPLETE CONFORMITY
WITH THE AUTHORISED ECONOMY STANDARD.

PRINTED IN GREAT BRITAIN BY PERCY BROS. LTD
THE HOTSPUR PRESS, MANCHESTER AND LONDON.

This book is dedicated to the men of the Royal Air Force who, undaunted by odds, unwearied in their constant challenge and mortal danger, turned the tide of the world war by their prowess and by their devotion in the Battle of Britain.

CONTENTS.

TABULATED DATA.

INTRODUCTION.

THIS report constitutes a summary of data resulting from the metallurgical examination of German and Italian aircraft engine and airframe parts by the Aero Components Sub-Committee of the Technical Advisory Committee of the Special and Alloy Steel Committee formed for this purpose.

The parts examined represent an extensive range of the various types of enemy aircraft which have fallen into the hands of the R.A.F. since the beginning of the war.

The principal object of these investigations was to obtain data on the types and quality of materials used, methods of manufacture, efficiency of the heat-treatment to which the parts had been submitted, together with any other information which might prove of value, as, for example, details of the finish. Further, the influence of restrictions due to our blockade on enemy procedure and selection of materials was kept in mind. Attention was given chiefly to engine parts, but a number of air-frame and miscellaneous components were included. Special features concerning design had been noted in certain instances, but these were not the primary object of the investigations.

For the purpose of this report, components of the same type from different aircraft have been considered together and the main features summarised. For fuller details the individual reports should be consulted.

The Sub-Committee responsible for these investigations and for this report comprise Mr. W. H. Dyson, Ministry of Aircraft Production; Dr. H. Sutton, Royal Aircraft Establishment; Dr. R. Genders, Superintendent, Technical Applications Metals, Ministry of Supply; Mr. H. Bull, Messrs. Brown-Bayley's Steel-works, Ltd.; Mr. H. H. Burton, the English Steel

Corporation, Ltd.: Dr. W. H. Hatfield, F.R.S., Chairman, Brown-Firth Research Laboratories: Mr. W. J. Dawson, Messrs. Hadfields, Ltd.: Mr. D. A. Oliver, Messrs. Wm. Jessop and Sons, Ltd.: Dr. T. Swinden, the United Steel Companies, Ltd.; and Mr. G. Stanfield, Secretary, Brown-Firth Research Laboratories.

The work included in this report embraces the results of investigations carried out from the beginning of the war until towards the end of 1941, but investigations have continued and are still in progress, and the work is being carried out meticulously. Naturally, no comparisons are made in the report with corresponding parts in British and American aircraft, neither are certain aspects, which the investigations have shown to be open to criticism, emphasised.

Since the preparation of this work, the Sub-Committee has suffered the loss of Dr. W. H. Hatfield, who was responsible for its inception and was closely associated with the large amount of work done, and of Mr. W. H. Dyson and Mr. G. Stanfield.

The Sub-Committee responsible for the continuance of the work comprises: Mr. H. Bull (Messrs. Brown Bayley's Steelworks, Ltd.), Mr. H. H. Burton (English Steel Corporation, Ltd.), Mr. W. J. Dawson (Messrs. Hadfields, Ltd.), Dr. Bruce Chalmers (Royal Aircraft Establishment), Mr. D. A. Oliver (Messrs. Wm. Jessop and Sons, Ltd.), Mr. L. Rotherham (Messrs. Thos. Firth and John Brown, Ltd.), Dr. H. Sutton (Ministry of Aircraft Production), Dr. T. Swinden, Chairman (United Steel Companies, Ltd.), and Miss M. K. Walshaw, Secretary (Brown-Firth Research Laboratories).

Section I—A Description of the Enemy Engines Examined

A BRIEF description of engines from which the parts examined were removed is of interest. The parts were taken from engines of four German series and one Italian. The German series comprised Jumo 211, Mercedes-Benz D.B. 601, B.M.W., and Bramo Fafnir. The first two engines are liquid cooled, and the second two air cooled. The Italian engine was the Fiat A80R.C. 41 radial engine.

Jumo 211 Series (German)

The engine from which most of the parts were obtained was of the Jumo 211A type. The engine had been installed in a Heinkel 111 aircraft. Engines of the Jumo 211 series are also used in Junkers 87 and Junkers 88 aircraft. Other engines of the Jumo 211 series – i.e., Jumo 211B, 211D, 211F, and 211H – are in general only slight modifications of the 211A type.

The engine is a 12-cylinder supercharged inverted Vee, with liquid cooling, direct fuel injection into the cylinders, and spark ignition. The general design of the engine follows established practice.

The weight of the engine is low in proportion to the swept volume, 1,450 lb. and 35 litres respectively, but on account of the relatively low maximum engine speed the power output per litre is also low.

The crank-shaft is of unusual design for a modern aero engine, the webs being in the form of flat plates extended to form balance weights. The plain and forked connecting rods are of normal design.

The cylinder liners are inserted in the cylinder block, and four long studs attached to ears near the crankcase end of the liner draw the liner against the cylinder head, into which it is spigoted. The pressure joint is made by a copper washer on a conical seating. Two rubber rings in grooves in the liner make the sealing joint between the liner and crankcase.

The valves for each cylinder bank are operated by a single camshaft driven by bevel and spur gears from the lower end of the auxiliary gearbox. The inlet and exhaust valves are of normal shape, the exhaust valves being sodium cooled, one exhaust valve per cylinder being fitted.

Lead bronze is used for the main crankshaft bearings and big end bearings, but the camshaft bearings and supercharger drive bearings are of aluminium-rich alloy.

The airscrew is driven through a spur-type reduction gear, the driving and driven gears being splined to the shafts and centralised by split bronze cones. The driven shaft is mounted on a roller race at the rear end and on a combined roller and thrust ball race at the front housing cover.

The engine is well made, and there was no evidence of the employment of methods to economise labour.

Mercedes-Benz D.B. 601 Series (German)

Mercedes-Benz D.B. 601 engines are fitted in Messerschmitt 109, Messerschmitt 110, Heinkel 113, Heinkel 111P, and Macchi C. 200 aircraft. Most of the parts examined were from an engine of the D.B. 601A type.

The engine is of the 12-cylinder inverted 60° Vee super-charged, petrol

injection, liquid-cooled type. The bore and stroke are 150 mm. and 160 mm. respectively. The swept volume is 33.9 litres, and the compression ratio 6.9/1. The net dry weight is 1,400 lb. The engine is mounted by means of steel pins screwed into aluminium alloy flanges, spigoted into two positions on each side of the crankcase and held by studs. Various types of forged magnesium alloy cantilever mounting-cradle arms are employed.

The crankcase is an aluminium alloy casting internally ribbed to provide rigidity with lightness. Seven main crankshaft bearing bridges are machined to take bearing caps, and the main bearings are lead-bronze lined steel shells. The crankshaft is hollow and in one piece, with balance weights riveted to most of the crankweb extensions. The connecting rod assembly consists of plain rods of I section and forked rods of H section that run on three track roller crankpin bearings. Each track has 24 rollers, housed in a split duralumin cage and running on the crankpin. The outer race is a split steel shell.

Each cylinder block, including the heads and double-walled jackets, is a single aluminium alloy casting with dry liners. Steel cylinder liners, the ends of which bed on to the cylinder head to make a gas-tight joint, are screwed and shrunk into the block.

Two exhaust and two inlet valves are fitted per cylinder. All have hollow stems and the exhaust valves are sodium cooled. There is one hollow under-head camshaft for each cylinder block.

The airscrew reduction gears are of normal type and incorporate a short steel sleeve, so disposed as to allow some self-alignment in transmission. The airscrew shaft is hollow, to provide for a cannon firing through it.

The supercharger impeller is driven through a hydraulic coupling, and its speed is automatically varied with altitude.

The fuel pressure pump delivers to an injection pump, which consists of 12 separate pumps mounted in line and driven by an overhead camshaft. A control unit regulates the fuel delivery to give a predetermined mixture for change of boost, change in exhaust back pressure, and change in temperature of the air in the inlet manifold.

The workmanship and casting technique are good, and the engine is designed and conspicuously marked for quick detachment from and replacement in the aircraft.

The Mercedes-Benz D.B. 601N engine is very similar to the D.B. 601A, except that the compression ratio has been raised to 7·9/1 and the allowable speed increased from 2,400 to 2,800 r.p.m.

B.M.W. 132K and B.M.W. 801A (German)

The B.M.W. 132K engine is installed in Heinkel 115 float plane aircraft. The engine is an air-cooled, geared, 9-cylinder radial, direct petrol injection engine, with single-speed supercharger. The airscrew is driven through epicylic reduction gearing. The cylinders have a $6\frac{1}{8}$ in. bore and $6\frac{7}{8}$ in. stroke (as the Pratt and Whitney Hornet engine), giving 27·7 litres swept volume. The compression ratio is 6·93/1.

The twin spur planet epicyclic reduction gearing for the airscrew provides a ratio of 44/61 times crankshaft speed. Accessories and auxiliaries are driven through several trains of spur pinions radially disposed about a central driving shaft in the auxiliary gearbox at the rear of the engine. The net dry weight of the engine is 1,170 lb.

The engine is mounted on a tubular ring held by welded tubular Vee bracing to the front spar of the main plane.

The crankcase, in two portions bolted together, is cast in aluminium alloy. The crankshaft is in two sections, the shaft and crankpin being integral with the forward crank web. The rear web

is bushed in the eye with an aluminium bronze liner, the bore of which is ground to a taper and highly burnished. The outer surface of the crankpin is ground with a high finish to a corresponding taper, on to which the crank web is pressed. The bore of the crankpin is inversely tapered on the same gradient to accommodate the insertion under a heavy load of a copper-plated steel-tapered plug which fits flush with the end of the crankpin. The tapered plug is internally threaded, presumably for extraction.

Eight auxiliary connecting rods of H section form a normal assembly articulated around the flanged big end of a master rod which carries a fixed steel bush lined with lead-bronze. The wrist pins are inserted from the front and located by locking plates. Gudgeon and wrist-pin bearings are phosphor bronze bushed.

The steel cylinder barrels and aluminium alloy heads are close finned, with a total radiating surface of about 20 sq. ft. The cylinder barrel is screwed and shrunk into the head.

The exhaust valves have hollow sodium-cooled heads and stems. The inlet valves are solid, with dished heads. The valve rockers are fitted with spun-in balls, flattened to make contact with the valve stems and held in screwed adjusters. They are mounted on fixed spindles in the bronze-bushed walls of the rocker-box. The rockers are actuated through ball-ended push rods and plain bearing roller tappets by cam-rings, one inlet and one exhaust. The cam-wheel is driven through a reduction gearing on the forward crankcase wall, giving a ratio of one-eighth crankshaft speed.

The front end of the crankshaft is internally bronze-bushed, to form a spigot bearing for the after end of the airscrew driving shaft, which operates through the reduction gear.

The B.M.W. 801A engine is a 14-cylinder, 2-row air-cooled radial engine. It is installed in Dornier 217 and Focke-Wulf 190 aircraft. Examination of this engine is not yet complete.

Bramo-Fafnir 323P 1 (German)

This engine is installed in Dornier 17/Z aircraft. The engine is a 9-cylinder radial, air-cooled, geared engine with petrol injection to the cylinders. It has a two-speed supercharger. The capacity is 26·8 litres, and the compression ratio is 6·23/1. The general design is conventional and includes American pattern cylinders, Farman type reduction gear, and bolt type Maneton jointed crankshaft. The engine weighs 1,320 lb. dry and 1,970 lb. when the airscrew, engine mounting, cowling and oil-cooler are included. The published take-off power is 989 h.p. (British units).

The crankcase proper is built up of two aluminium alloy pressings which are faced to join on the centre line of the cylinders. Steel housings for the main crankshaft bearings are pressed into the front and rear walls of the crankcase and pinned.

The steel cylinder barrels are screwed and shrunk into the aluminium alloy heads without any joint or locking device.

The exhaust and inlet valves are hollow, the former being sodium-cooled. The valves are operated by a cam-ring mounted concentrically with the crankshaft in a chamber in the front of the crankcase. The crankshaft is of conventional design, the two principal portions being joined together by a Maneton joint of normal type. The connecting rod assembly also is of normal type. The big end of the master rod runs on a lead-bronze bearing cast on a steel bush, which is shrunk on the crankpin and located by a dowel. The articulated rods are of uniform H section with fixed bronze bushes at both ends.

The airscrew reduction gear consists of an epicyclic train of bevel wheels and provides a ratio of 29 : 18.

The supercharger is driven from the rear of the crankshaft through a spring

coupling and an epicyclic step-up gear that is arranged to give two alternative ratios, 9·6 : 1 and 12·4 : 1.

The engine mounting is a triangulated structure of the usual type, built up by welding.

Fiat A.80 R.C.41 (Italian)

The engine examined had been installed in a Fiat B.R. 20 twin-engined bomber. The engine is of the 18-cylinder double row supercharged air-cooled radial type, fitted with reduction gearing. The compression ratio 6·7/1. The cylinder bore is 140 mm. × 165 mm., and the swept volume 72 litres. Unlike the German engines examined, this engine employs a carburettor. The supercharger is of the single-speed type. The engine is of conventional design throughout, and has a very low power output per litre.

Section II—Crankshafts

THE eight crankshafts examined, taken from various types of German and Italian engines and aircraft, were of the following types:—

Six-throw Crankshafts

Report No. 1.—Junkers Jumo 211A (front portion only; see Fig. 1).

Report No. 19.—Mercedes-Benz D.B. 601A (see Fig. 2).

Report No. 85.—Mercedes-Benz D.B. 601N. (see Fig. 3).

Report No. 124.—Junkers Jumo 211F 1 (see Figs. 4 and 5).

Report No. 132.—As Report No. 124 (portion only; not illustrated).

Radial Crankshafts

Report Nos. 13 and 28.—B.M.W. 132K engine (see Figs. 6 and 7).

Report No. 44.—Bramo Fafnir 323P engine (see Figs. 8 and 9).

Report No. 82.—Fiat A80RC 41 (front half only; see Fig. 10).

With the exception of the last mentioned, Report No. 82, the crankshafts were all of German origin.

In general, the surface finish and workmanship throughout were of a high order, and during the preliminary examination no fatigue flaws, cracks or defects were found. The centre journal of Report No. 19 showed severe overheating, probably owing to loss of lubrication, and the appearance of the pin of the Fiat crankshaft (Report No. 82) indicated heavy bearing pressures.

TABLE I.—CHEMICAL ANALYSES OF THE CRANKSHAFTS.

SIX-THROW TYPE.

Report No.		C. %	Ni. %	Cr. %	Mo. %	V. %
1	Junkers Jumo 211A	0·30	1·45	2·48	0·24	0·08
19	Mercedes-Benz D.B. 601A	0·18	1·78	1·85	0·34	Nil
85	Mercedes-Benz D.B. 601N	0·20	1·99	1·72	0·30	Nil
124	Jumo 211.F.1	0·31	2·03	2·44	0·22	0·12
132	Jumo 211.F.1	0·28	1·48	2·53	0·16	Nil

RADIAL TYPE.

Report No.		C. %	Ni. %	Cr. %	Mo. %	V. %
28	B.M.W. 132K—Front half		1·92	2·14	0·25	Nil
13	Rear half	[illegible]	0·28	1·19	0·21	Nil
44	Bramo F. 323P—Front half	[illegible]	1·84	2·10	0·30	Nil
	Rear half	[illegible]	1·89	1·90	0·37	Nil
	Fiat A.80RC.41—Front half	[illegible]	3·02	0·73	0·36	Nil

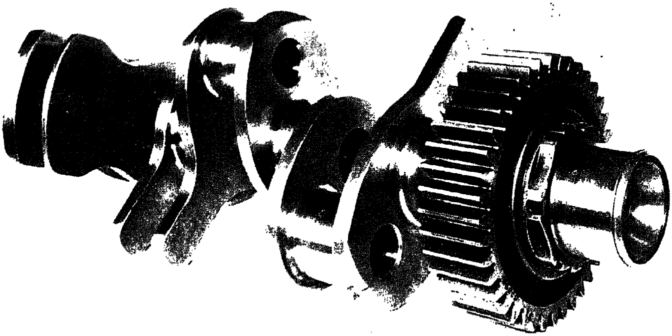
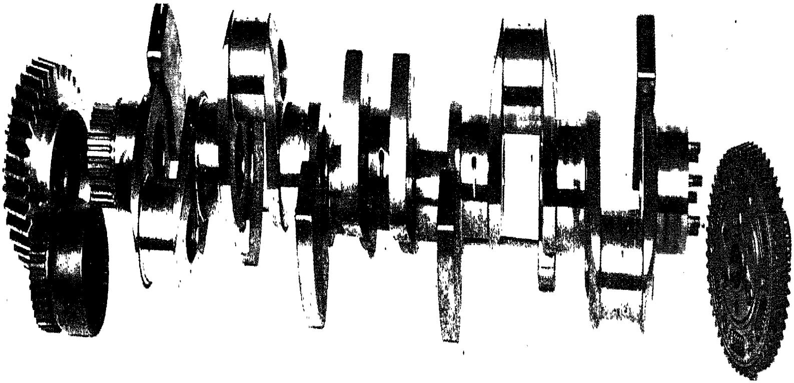


Fig. 1. Front portion of Junkers Jumo 211A.

Fig. 2.—Mercedes-Benz D.B. 601A.



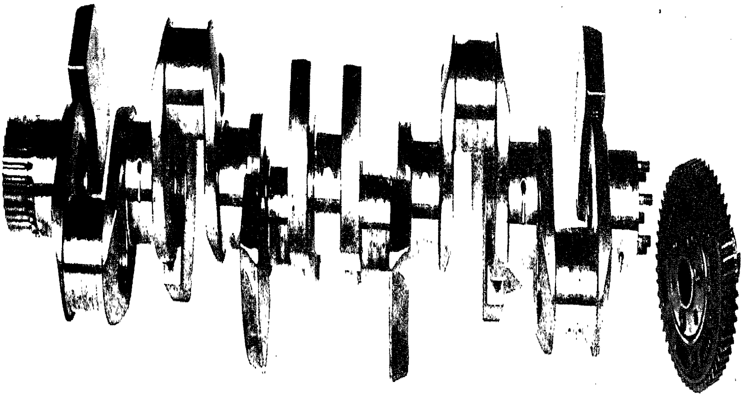
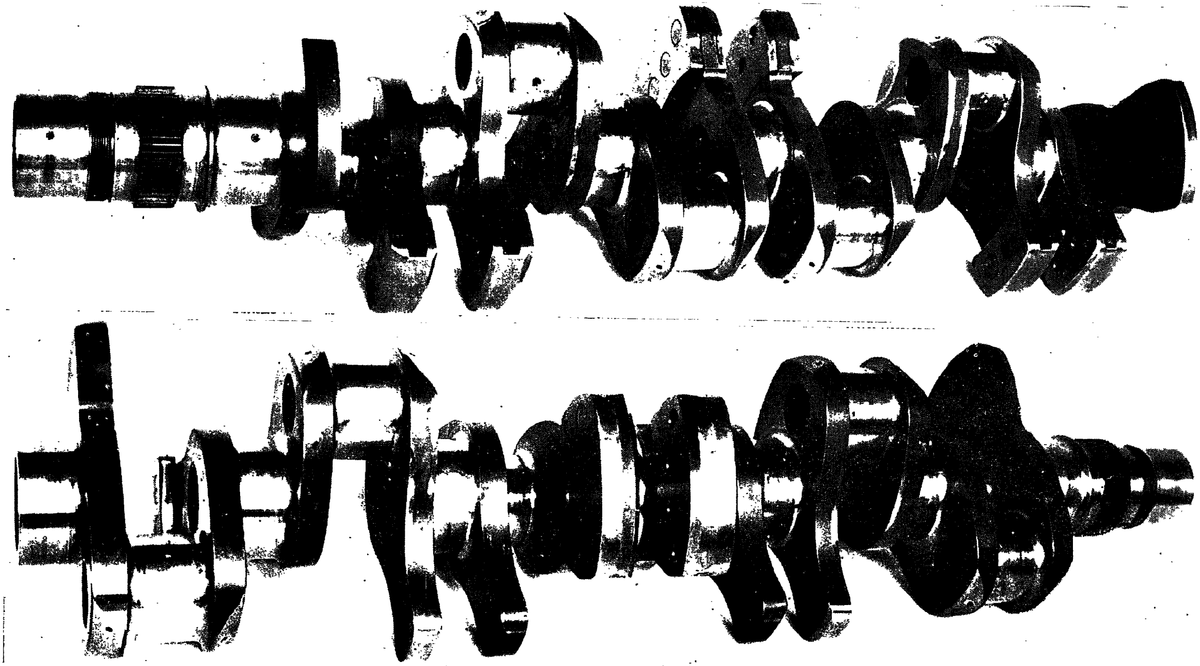
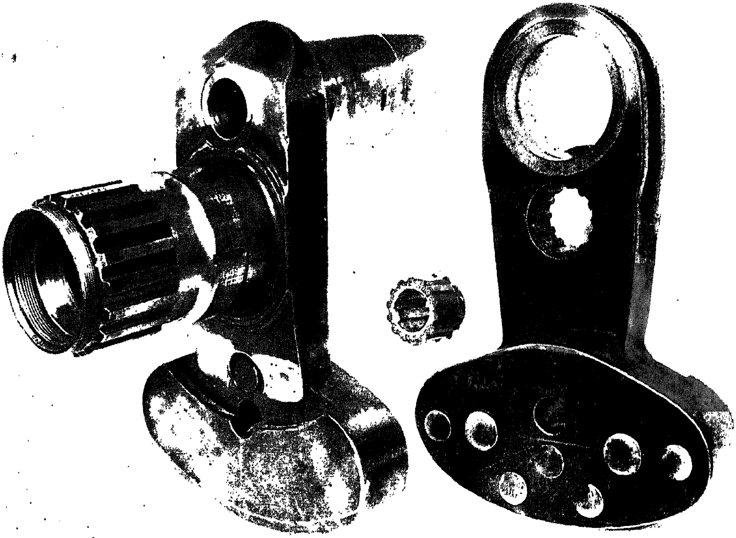


Fig. 3.—Mercedes-Benz D.B. 601N.



Figs. 4 and 5.—Junkers Jumo 211F 1.



Figs. 6 and 7.—B.M.W. 132K engine.

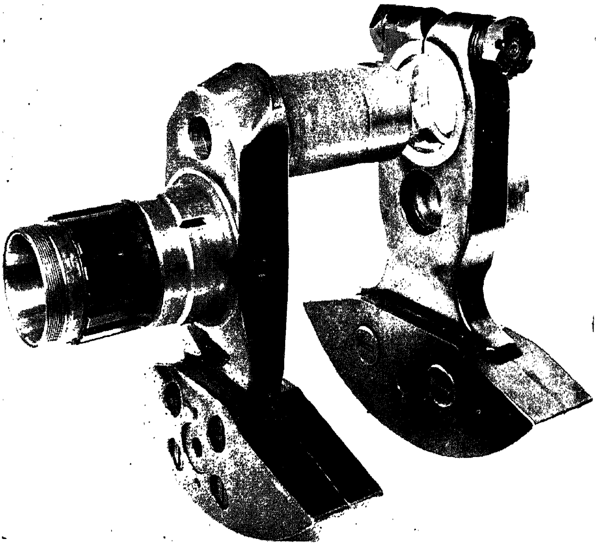


Fig. 8.
Bramo
Fafnir
323P
engine.

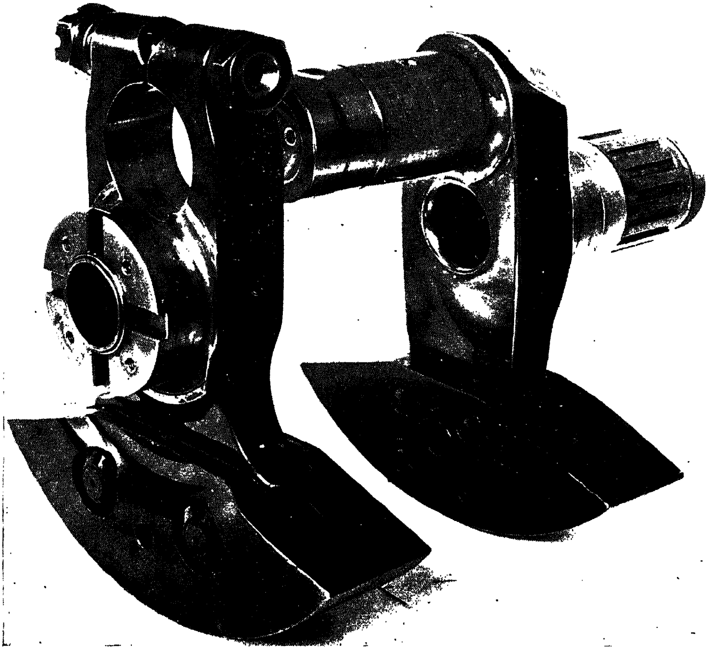


Fig 9.—Bramo Fafnir 323P engine.

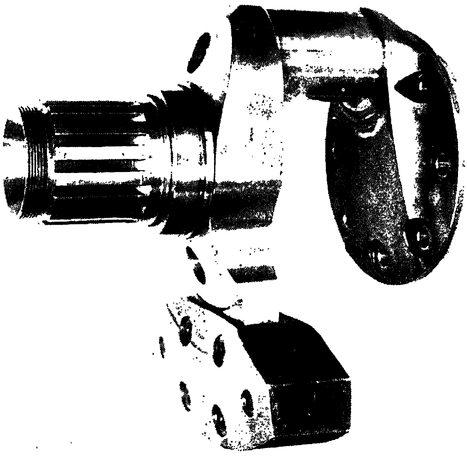


Fig. 10.—
Front
portion of
Fiat A.
80R.C.41

Chemical Analysis

The results of the chemical analysis of the crankshafts are summarised in Table I.

Both the nickel and the chromium contents fall approximately within the range of $1\frac{1}{2}$ to $2\frac{1}{2}$%, with two exceptions—namely, the rear half of the B.M.W. 132K crankshaft, which was a 1% chromium-molybdenum steel, and the Fiat A.80 R.C. 41 front half, which contained 3% of nickel and $\frac{3}{4}$% of chromium with molybdenum. An addition of vanadium was not usual, and was found only in two of the three Jumo crankshafts.

The samples can be further classified into carburised and non-carburised, and it will then be seen that the carbon content of the carburised steels varies from 0·16–0·20%, and for the non-carburised the carbon content ranges from 0·28-0·38%.

All the steels appeared to have been made by the basic electric arc process.

Heat-treatment and Microstructure

The crankshafts may be classified again as follows :—

NON-CARBURISED.

Report No. 1—Junkers Jumo 211A.
,, 13—B.M.W. 132K rear half.
,, 44—Bramo F. 323P, rear half.
,, 82—Fiat A. 80 R.C. 41, front half.

CARBURISED.

Report No. 19—Mercedes - Benz D.B. 601A.
,, 85 Mercedes - Benz D.B. 601N.
,, 28—B.M.W. 132K, front half.
,, 44 Bramo F. 323P, front half.

NITRIDED.

Report No. 124—Jumo 211F 1.
,, 132—Jumo 211F 1.

Report No.	Crankshafts	Depth of Case.	Max. Hardness
19	Mercedes-Benz D.B. 601A	0·15 in.	730 V.P.N.
85	Mercedes-Benz D.B. 601N	0·20 in.	830 ,,
28	B.M.W. 132K—Front half	0·15 in.	800 ,,
44	Bramo F. 323P—Front half	0·05 in.	730 ,,

The sulphur and phosphorus contents were low and ranged from 0·008 to 0·016% ; the standard of cleanness was high, similar to that being supplied to the British aeroplane industry.

Method of Manufacture

Representative sections were prepared for sulphur printing and etching. No segregation was revealed, and the carburisation of pins and journals of those crankshafts which had been carburised was uniform, Fig. 11. Further etching with a cupric reagent revealed a normal grain flow for stampings, but in general the allowance for machining appeared to have been greater than is usual in this country. Ink prints were prepared, and the dendritic structures generally indicated the use of a comparatively small size of ingot.

The crankshafts which had not been carburised appeared to have been hardened and tempered in a normal manner, the microstructures consisting of sorbite. The front end of the early Jumo crankshaft had been overheated slightly for hardening, but the other crankshafts of this group possessed fine-grained structures.

The total depth of carburisation was determined by micro-examination and by depth hardness and carbon determinations. Fig. 12 shows the results obtained on the Mercedes-Benz crankshaft.

The small amount of free carbide was in a finely divided form, and it is probable that there had been a diffusing heat-treatment after carburising. Both case and core structures of the above crankshafts were fine grained, and indicated a refining and hardening

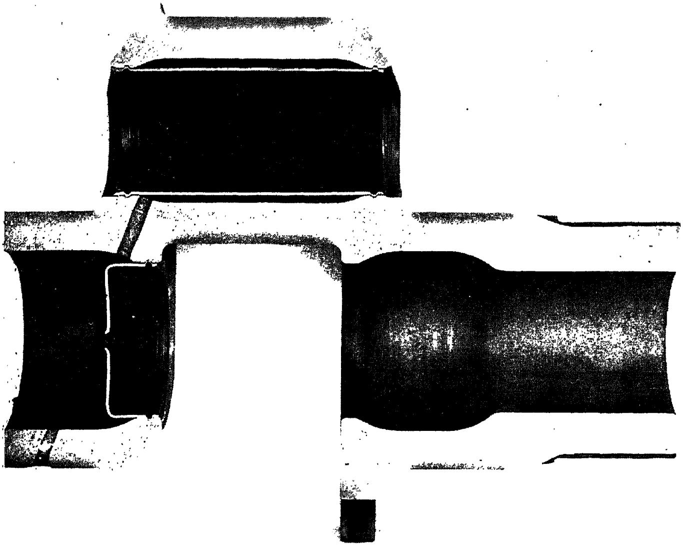


Fig. 11.—Section of Mercedes-Benz D.B. 601N, showing structure.

heat-treatment from the usual temperatures. The final heat-treatment probably consisted of a tempering at about 200° C.

The early Jumo crankshaft (Report No. 1) had not been surface hardened, but the two Jumo 211F 1 crankshafts, although made from the same type of nickel-chromium-molybdenum steel, had been nitrided. This steel cannot be classed as a nitriding steel, and very considerable embrittlement had occurred.

A pronounced difference in depth of nitrided case was found, as shown by the hardness depth curves seen in Fig. 13. The case of greater depth possesses a lower maximum hardness, as shown by the curves. This was probably due to the use of an excessive nitriding temperature. A comparison of the nitrided cases (Figs. 14 and 15) will show that the crankshaft (Report No. 124) possessed an abnormally large heat-treated grain size, and it was evident that the crankshaft had been overheated for hardening prior to nitriding.

Mechanical Properties

Tensile and impact tests were prepared from several positions in the crankshafts. The widest variation in maximum stress was found in the case carburised crankshaft from the Mercedes-Benz D.B. 601N engine, from which maximum stress values of 84 and 91·7 tons per sq. in. were obtained.

The following figures were selected from results of tests taken where the grain flow was longitudinal, but other tests were taken in a transverse direction, and these did not reveal any marked fall in ductility or toughness.

The tensile results do not call for comment, but with reference to the Izod results it should be noted that the rear half of the B.M.W. 132K crankshaft (Report No. 13) was made from a $1\frac{1}{4}\%$ chromium-molybdenum steel.

Reference has already been made to the embrittlement of the nitrided crankshafts (Report Nos. 124 and 132).

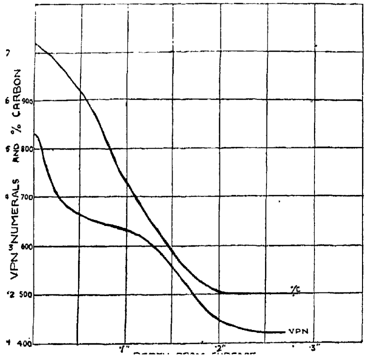


Fig. 12.—Depth of carburisation on Mercedes-Benz D.B. 601N.

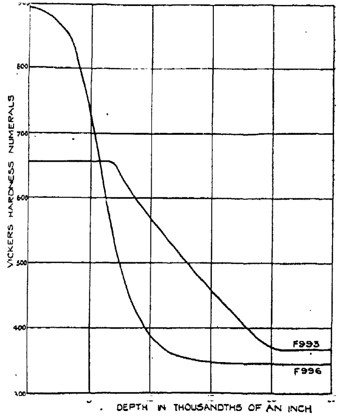


Fig. 13.—Depth of nitriding on Junkers Jumo 211F 1.

Peculiarities of Design

Among the six-throw crankshafts, it will be noticed that the early Jumo crankshaft (Report No. 1), see Fig. 1, did not carry attached balance weights. All of the pins and journals were chambered, and the pins had been bored eccentrically.

The balance weights attached to the Mercedes-Benz D.B. 601A and D.B. 601N crankshafts consisted of three pieces riveted together, and rather heavier in the last-mentioned crankshaft (compare Figs. 2 and 3). The pins and journals had been bored and chambered concentrically. Mild steel tubes had been fitted inside the pins of these two crankshafts, and end caps of similar material had also been fitted to the journals of the Mercedes-Benz D.B. 601N crankshaft, as shown by the halt section, Fig. 11.

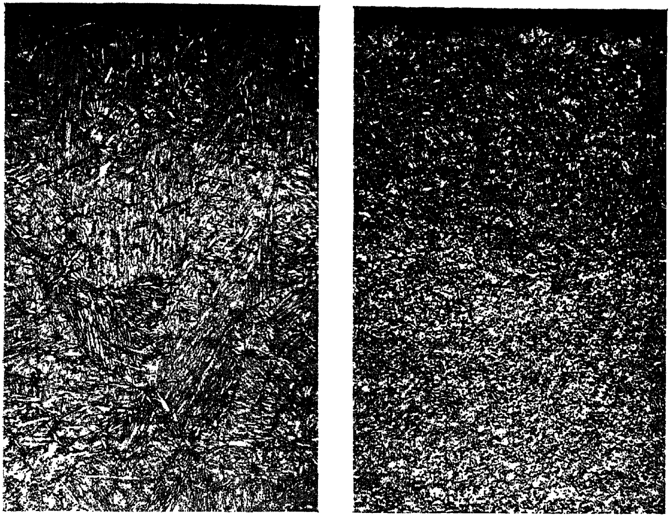
It was also noticed that oil holes on the journals of the D.B. 601N crankshaft had been moved circumferentially 120° or 180°.

Both these crankshafts of Reports Nos. 19 and 85 carried a spring drive, which is shown with the crankshafts in photographs (Figs. 2 and 3), and one of them is shown dismantled in Fig. 16.

The two Jumo 211 F. 1 crankshafts were of similar design and were of unusually heavy construction. The radii of both pins and journals were most generous. The pins and journals had been chambered, and the pins had been bored eccentrically as with the early

TABLE II.—MECHANICAL PROPERTIES OF THE CRANKSHAFTS.

Report No.		Max. Stress, Tons/sq./in.	Elongation	Izod Impact Ft.-lb.
	NOT CARBURISED.			
1	Junkers Jumo 211A		20·8	
13	B.M.W. 132K—Rear half	67·	19·0	
44	Bramo F. 323P—Rear half	73·	18·5	46
82	Fiat—Front half, A.80,R.C. 41	74·	20·4	18, 51
	CARBURISED.			
19	Mercedes-Benz D.B. 601A		19·5	
85	Mercedes-Benz D.B. 601N	84·9	17·5	51
	B.M.W. 132K—Front half	81·6	19·6	55, 65
	Bramo F. 323P—Front half ...	86·7	17·3	49, 46
	NITRIDED.			
124	Jumo 211.F.1	70·0	16·0	10, 11
132	Jumo 211.F.1	67·0	18·5	18, 19



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Figs. 14 and 15.—Comparison of the nitrided cases of two Junkers Jumo 211F 1 crankshafts. x 250.

Jumo crankshaft. Each of the added balance weights was in one piece, riveted to the crankshaft.

Evidence of hammering and local grinding or dressing after hammering was found on several web faces of both crankshafts. One of these is shown in Fig. 17. It will be remembered that these two crankshafts had been nitrided, and it has been suggested that distortion had occurred during nitriding, and that the hammering was a part of a straightening operation.

All the crankshafts from the radial engines carried attached balance weights, which in the B.M.W. 132K and Fiat A 80 R.C. 41 had been riveted, (see Fig. 18, showing the rear half of the B.M.W. 132K crankshaft after dismantling), but the balance weights of the Bramo Fafnir 323P crankshaft had been bolted (see Figs. 19 and 20).

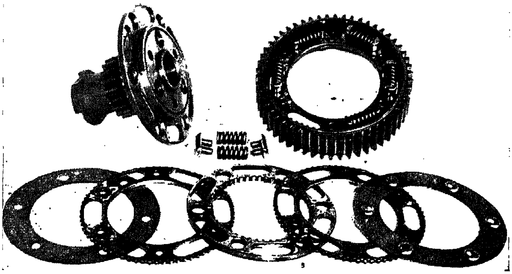
With the exception of the Fiat A. 80.R.C. 41 crankshaft in the construction of which a brass casting has been used, all the balance weights were carbon steel forgings riveted with mild steel, but the bolts on the Bramo Fafnir 323P crankshaft were in alloy steel. Those on the front half, see Fig. 19, were of $2\frac{1}{2}\%$ chromium-molybdenum steel, and those in the rear $1\frac{3}{4}\%$ nickel 2% chromium with molybdenum. The latter bolts had been nitrided without embrittlement.

The two halves of the Bramo Fafnir 323P crankshaft were connected by a Maneton joint, as shown in Figs. 8 and 9. The Maneton bolt had been bored out and very finely finished, and was of the following composition :

	%
Carbon	0·46
Chromium	1·68
Molybdenum	0·36
Vanadium	0·21

heat-treated to 89 tons tensile strength, with an equivalent Izod figure of 23 ft.-lb. The nut was made from a $2\frac{1}{2}\%$ chromium - molybdenum steel

Fig. 16.—Dismantled spring drive for Mercedes-Benz crankshaft.



hardened and tempered to about 70 tons tensile strength, and a washer was of 2% beryllium-copper, having an equivalent tensile strength of about 65 tons per sq. in.

Among the auxiliary parts examined, the starter shaft (Report No. 29) fitted to the rear half of the B.M.W. 132K crankshaft was of special interest. The overall length of the shaft was 13½ in. and 1 in. diameter in the shaft portion. Fig. 21.

The chemical analysis was as follows :—

	%
Carbon	0·18
Manganese	1·07
Nickel	0·18
Chromium	1·26
Molybdenum	0·27

Both ends of the shaft had been formed by an upsetting operation, and both splined portions and the hand-starter dogs had been locally carburised. Subsequently, the shaft as a whole had been given a case-hardening heat-treatment involving a final quench in water from about 800° C. As a result the carburised portions were fully case-hardened, and the shaft showed a hardness gradation having an equivalent tensile strength of 100 tons per sq. in. at the surface to 72 tons tensile at the axis.

General Conclusions

The examination of several crankshafts taken from German and Italian aeroplane engines has not disclosed any

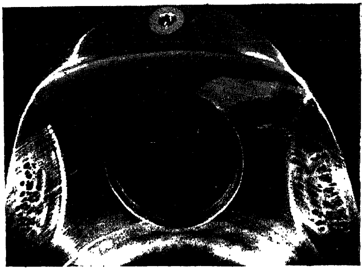


Fig. 17.—Evidence of hammering and local grinding found on web faces of two Jumo 211F 1 crankshafts.

novel features of design, but has shown that they were made from materials of first-rate quality. There has been no evidence to indicate any shortage of alloying metals.

The early Junkers Jumo six-throw crankshaft and three others quoted on page 12 were not case-hardened, but the remaining crankshafts had been case-hardened after carburising the pins and journals, and only the most recently examined Jumo 211F 1 crankshafts had been nitrided. It is surprising that the enemy should have been so slow to realise the advantages of nitriding.

The crankshafts appear to have been made by drop-forging in a manner similar to that employed for aero crankshafts in this country. Most of the six-throw crankshafts had been fitted with separate balance weights, and it is

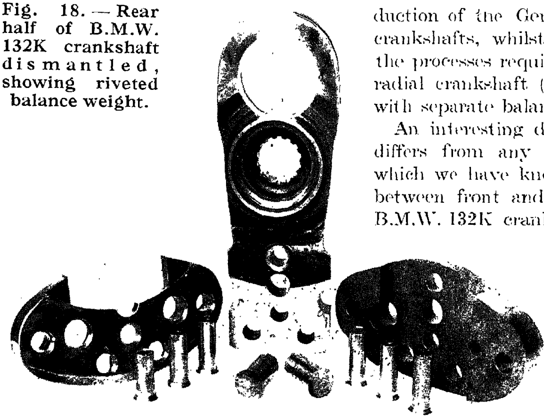


Fig. 18.—Rear half of B.M.W. 132K crankshaft dismantled, showing riveted balance weight.

thought that the object of this was to simplify the drop-forging process, which is always more difficult with large integral balance weights than with the much lighter type provided on most of these German components. We assume that, in some cases, one die operation might be saved by adopting the German design, but on the other hand machining processes would be increased, and it is probable that the final crankshaft is less satisfactory than one in which the balance weights are integral with the rest of the shaft. Figs. 19 and 20 illustrate the complicated machining processes for bolts and balance weights which would be necessary in the production of the German type of radial crankshafts, whilst Fig. 18 illustrates the processes required in the case of a radial crankshaft (B.M.W. 132K fitted with separate balance weights).

An interesting design feature which differs from any British practice of which we have knowledge is the joint between front and rear halves in the B.M.W. 132K crankshaft.

The reason for the peculiar design of the Italian Fiat A. 80. R.C.41 crankshaft is not known with any certainty, but it seems probable that the intention has been to avoid the Maneton type of joint, of which there would usually be two in a double row engine. Assuming that the large diameter coupling in the centre is used as a bearing, however, the possibility of very high peripheral speeds seems likely to be a disadvantage. It should also be noted that the Italian design necessitates the employment of a split master rod as compared with the solid-ended rod, which can be used with the Maneton joint coupling.

The heat-treatment in most instances had been effectively performed, but two cases of overheating for final hardening were found, and an excessive nitriding temperature also appeared to have been

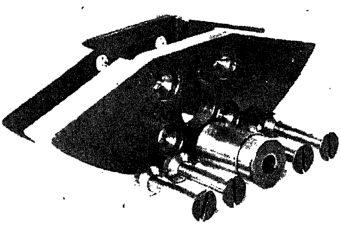


Fig. 19.—Front half of balance weights of Bramo Fafnir 323P crankshaft dismantled, showing bolt fixings.

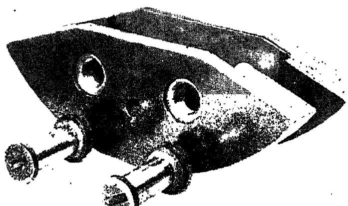


Fig. 20.—Rear half of balance weights of Bramo Fafnir 323P crankshaft.

Fig. 21.—Starter shaft fitted to the rear half of the B.M.W. 132K crankshaft.

used for one of the Jumo 211F 1 crankshafts.

Mechanical testing revealed high values for ductility and toughness commensurate with the tensile strength of the materials except for the two nitrided crankshafts. In these the impact values had dropped from an original estimated figure of 70 ft.-lb. to as low as 10 ft.-lb. It should be noted that, in our experience, the steel could not be classed as a satisfactory nitriding steel.

Some interesting features were found in the Bramo Fafnir 323P crankshaft, which was constructed with a normal type Maneton joint. The Maneton bolt was of unusually high-tensile strength (89 tons/sq. in.), and a beryllium-copper washer was used in conjunction with the nut, the latter being heat-treated to 70 tons tensile strength.

The conservation of oil by rolling in tubes of mild steel into the chambered pins of the Mercedes-Benz crankshafts, forming an annular space, was of interest.

The two Jumo 211F 1 six-throw crankshafts most recently examined were the heaviest aeroplane crankshafts we have yet seen, and all the radii were exceptionally generous.

In most cases the workmanship was of a high order, and in this respect the only exception which could be made was the very severe hammering for straightening which had apparently been given after nitriding to the two Jumo 211F 1 crankshafts.

The series of German crankshafts seems to include three stages of development, commencing with a non-hardened type and passing through a carburised and case-hardened type to the two nitrided shafts, which were the last examined. It is most surprising in view of the liking shown by the Germans for the 2.5% chromium-molybdenum steel in other directions, that a similar steel had not been employed for any of the aero crankshafts dealt with in this report. Since this summary was issued several examples of crankshafts in such steel have been found, but the adoption of this steel seems to have proceeded in Germany much more slowly than in Britain.

Section III—Connecting Rods

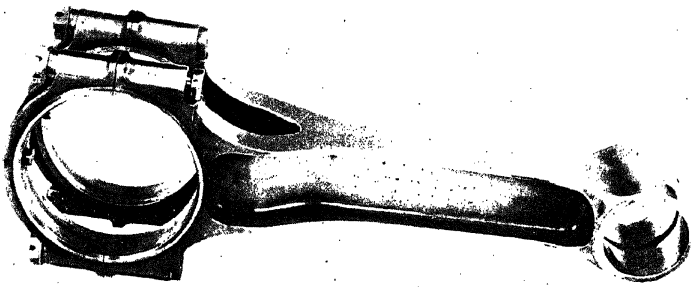
THE nine engines examined included seven types of German rods and one Italian, two of the them being in the nature of duplicates for checking purposes.

Types of Rod

Three of the engines (B.M.W 132K, Bramo Fafnir 323P, and Fiat A. 80 R.C. 41) were of the radial type, involving a "master" and auxiliary rods. In each of the other engines (Jumo 211A, B 1, F 1, and Mercedes-Benz D.B. 601A and D.B. 601N) there were two types of rod, one having a single " big end " and the other a double " big end," one of each type worked together on one pin, as seen in Fig. 25(*a*). The types illustrated in Figs. 22 to 27 were as follows :—

Fig. 22.—Jumo 211A (Report No. 4).
Fig. 23.—Jumo 211.F.1 (Report No. 115).
Fig. 24.—B.M.W. 132K (Report No. 14).
Fig. 25.—Mercedes-Benz D.B. 601A (Report No. 21).
Fig. 26.—Bramo Fafnir 323P (Reports Nos. 41 and 42).
Fig. 27.—Fiat A. 80R.C.41 (Report No. 81).

Fig. 22a.—Jumo 211A, double " big-end " rod.



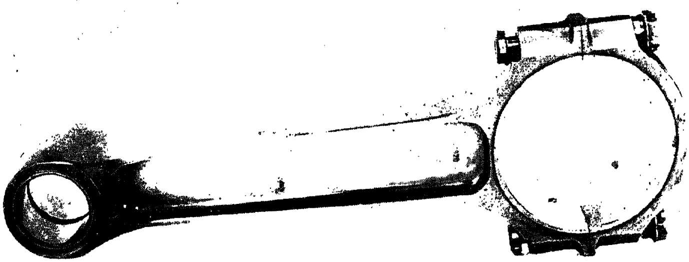
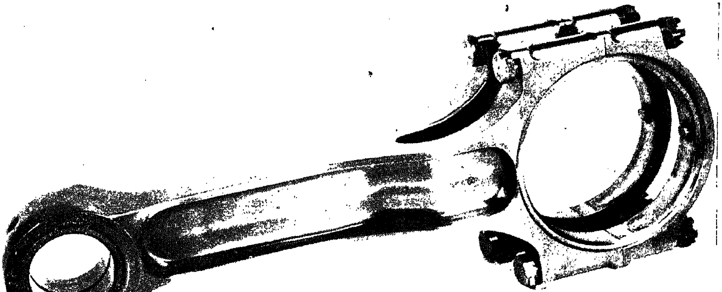


Fig. 22b.—Jumo 211A, single " big-end " rod.

Fig. 23a.—Jumo 211F 1, double " big-end " rod.



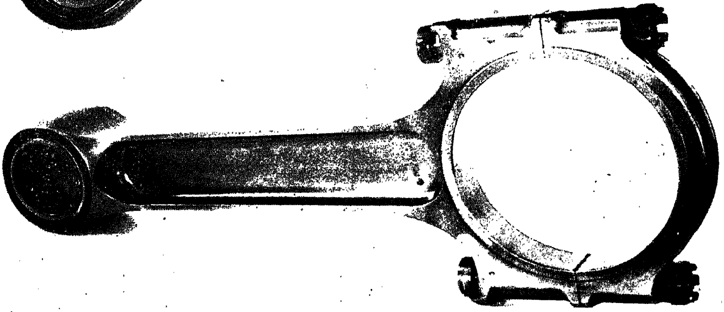


Fig. 23b.—Jumo 211F 1, single " big-end " rod.

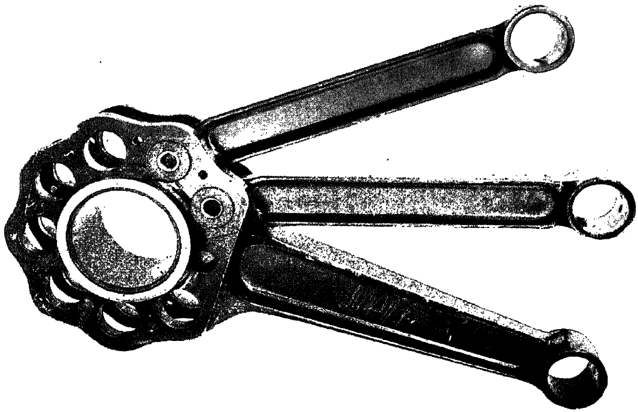
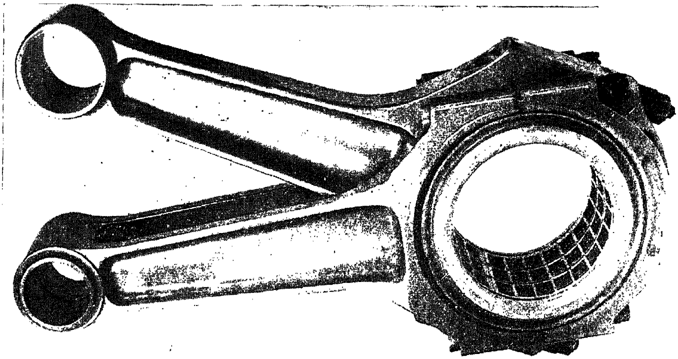


Fig. 24.- B.M.W. 132K.

Analyses

As regards composition, steels were either 2/2 nickel - chromium - molybdenum steel or 1 to $1\frac{1}{2}$ chromium-molybdenum, except in the Italian engine, where the materials were of the $2\frac{1}{2}$ nickel-chromium and $2\frac{1}{2}\%$ nickel-chromium-molybdenum types. One later type of Jumo engine (F.1) (Report No. 115) was found to be more of the $2\frac{1}{2}/1\frac{1}{2}$ nickel-chromium type with both molybdenum and vanadium.

Fig. 25a.—Mercedes-Benz D.B. 601A, two rods on one pin.



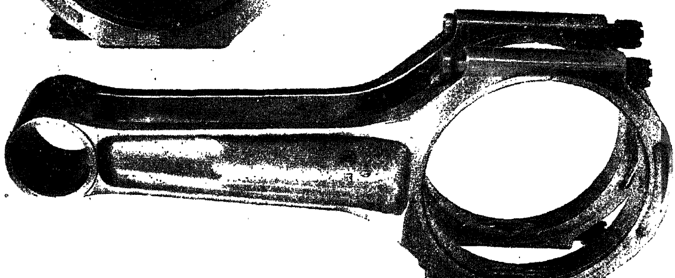
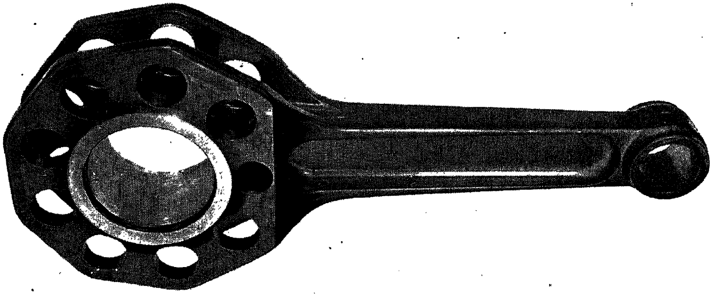


Fig. 25b (centre).—Mercedes-Benz D.B. 601A, single "big-end" rod.
Fig. 25c. Mercedes-Benz D.B. 601A, double "big-end" rod.

Fig. 26a.—Bramo Fafnir 323P, master rod.



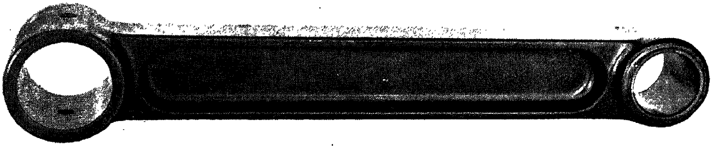
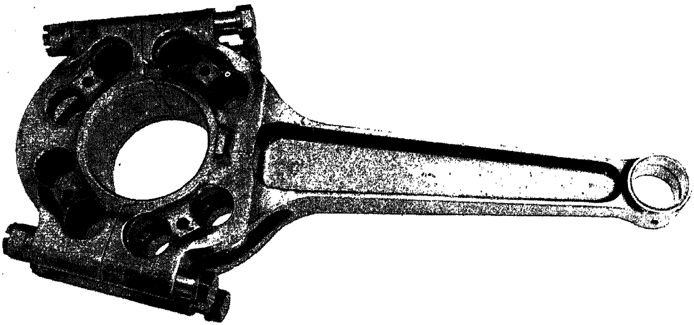


Fig. 26b.—Bramo Fafnir 323P, auxiliary rod.

Fig. 27a.—FiatA. 80R.C.41, master rod.



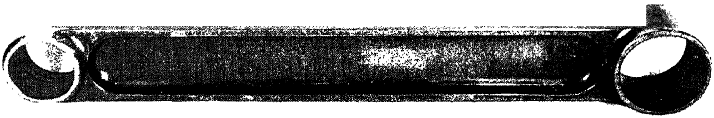


Fig. 27b.—Fiat A. 80R.C.41, auxiliary rod.

The bolts were of similar composition to the rods, except in the Mercedes-Benz D.B. 601A and the later Jumo 211F 1 engines. In the former the bolts were made from a low-carbon $4\frac{1}{2}\%$ nickel-chromium steel, case carburised, while the latter approximated to $2\frac{1}{2}\%$ chromium-molybdenum. The nuts were essentially chromium - molybdenum steels with the exception of one $1\frac{1}{2}\%$ nickel-chromium steel.

Other auxiliary parts consisted of a stud for locking purposes of $3\frac{1}{2}\%$ nickel-chromium steel, nitrided wrist pins of $2\frac{1}{2}\%$ chromium - molybdenum steel, a roller race and roller bearing of high - carbon - chromium steel, and a bearing shell of low - carbon steel lined with lead bronze. Details of compositions and mechanical tests are given in Table III.

Mechanical Tests

In general, the maximum stress values were between 65 and 75 tons per sq. in., although the later Jumo 211F 1 single rod, already mentioned, had a tensile strength of 83 tons per sq. in. The Fiat rod and one German rod were in the region of 60 tons per sq. in. The hardnesses on the surfaces showed appreciable variation, and on one of the Fiat rods a zone of lower tensile strength gave only 53·9 tons per sq. in. The ductilities accompanying the tensile strength were all of a very high standard, e.g., 20% elongation and upwards for 65 to 75 tons per sq. in., with Izod values generally above 50 ft.-lb., and in some cases up to 80 ft.-lb.

Manufacture of Steel

Cleanliness was in most cases of a very high standard, and no marked deterioration in the quality of the later Jumo engine materials was observed. Of the 33 samples analysed for sulphur, 16 gave values below 0·01% and 11 others below 0·02%.

It is concluded from the general analyses, cleanliness and results of gas analyses, that the steels are essentially basic electric steels. The rods of the Mercedes - Benz D.B.601 N. and the B.M.W. 132K (Reports Nos. 86 and 14) were of less clean steel, and these may have been made of acid open hearth steel.

Fig. 28a.—Flow structure of Jumo 211A single big-end rod.

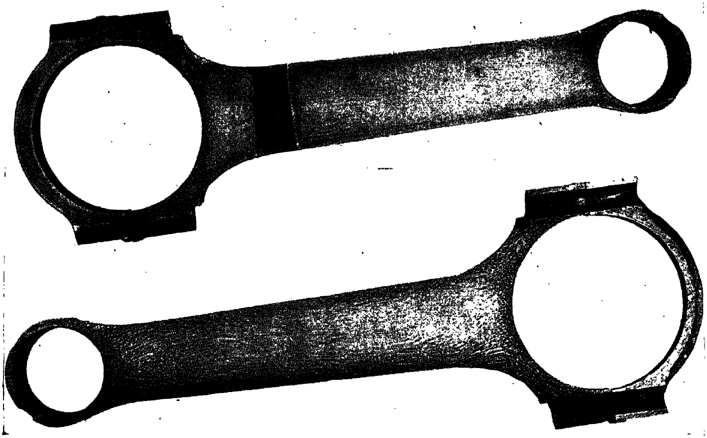


Fig. 28b.—Flow structure of Jumo 211A double big-end rod.

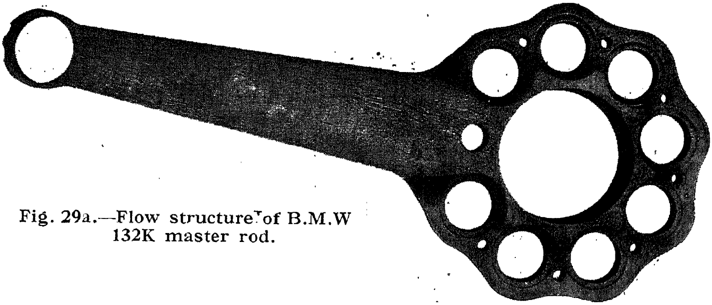


Fig. 29a.—Flow structure of B.M.W 132K master rod.

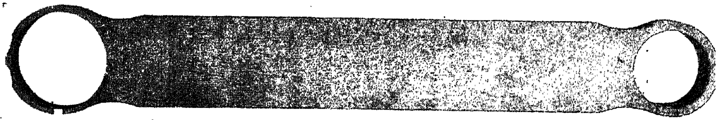
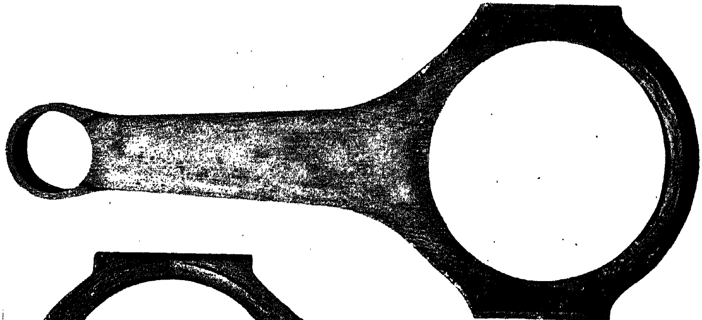


Fig. 29b.—Flow structure of B.M.W 132K auxiliary rod.

Fig. 30a.—Flow structure of Mercedes-Benz D.B. 601A single big-end rod.



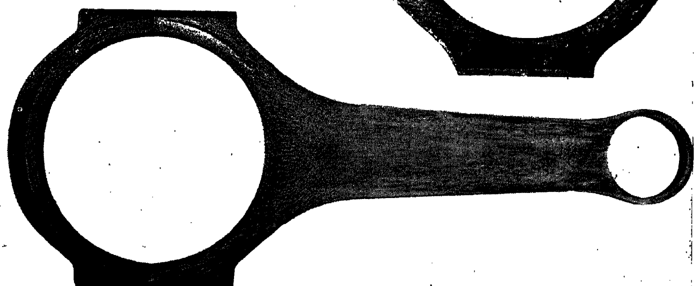


Fig. 30b.—Flow structure of Mercedes-Benz B.D. 601A double big-end rod.

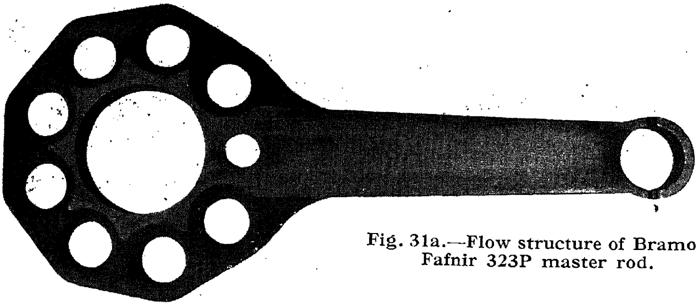


Fig. 31a.—Flow structure of Bramo Fafnir 323P master rod.

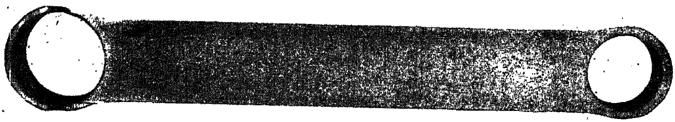


Fig. 31b.—Flow structure of Bramo Fafnir 323P auxiliary rod.

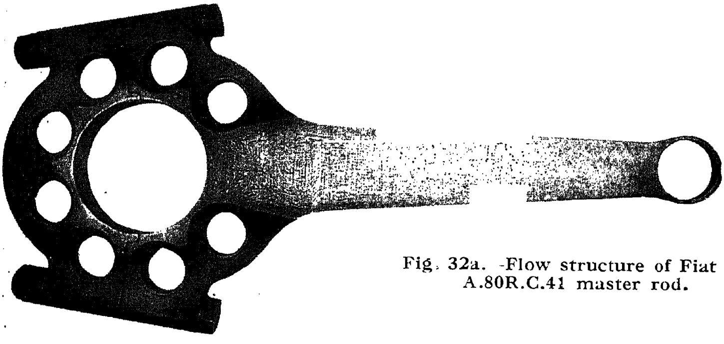


Fig. 32a. -Flow structure of Fiat A.80R.C.41 master rod.

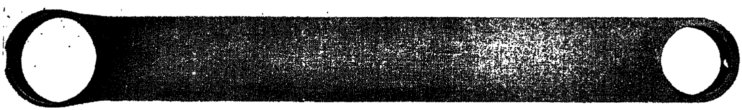


Fig. 32b.—Flow structure of Fiat A.80R.C.41 auxiliary rod.

Fig. 33.—Microstructure of Jumo 211A double big-end rod. x 200.

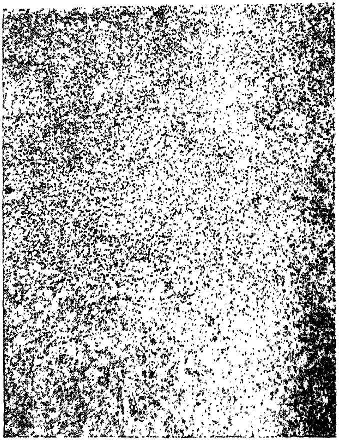


Fig. 35.—Microstructure of Mercedes-Benz D.B. 601A double big-end rod. x 200.

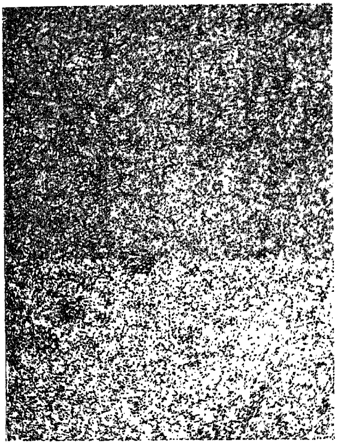


Fig. 34.—Microstructure of B.M.W. 132K master rod. x 200.

Fig. 36.—Microstructure of Bramo Fafnir 323P master rod. x 100.

Accessories

These are dealt with under the headings of Wrist Pins and Bearings. Details of bolts and nuts are given in Table III.

General Remarks

The chief features learned from these rods are :—

(*a*) Preference for two types of composition, 2/2 nickel-chromium-molybdenum and $1\frac{1}{4}$ chromium-molybdenum steel.

(*b*) High standard of cleanliness with resulting good mechanical properties—i.e., high ducility and impact for 65 to 75 tons per sq. in. condition.

(*c*) No deterioration as regards quality had occurred in the later Jumo 211F 1 engine parts (Nos. 115 and 126) belonging to planes shot down in September and November, 1941. In the case of No. 115, a modification had been brought about by the addition of vanadium.

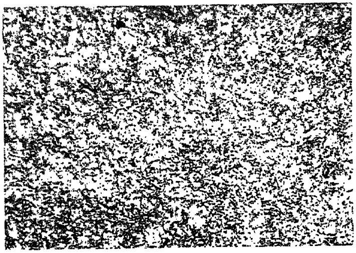


Fig. 16.—Microstructure of Fiat A. 80 R.C.41 master rod. x 200.

The relatively high copper content of the Jumo 211.F.1 single big end and bolts (Report No. 115) is interesting.

Section IV—Gudgeon Pins and Wrist Pins

TEN gudgeon pins and two wrist pins, representing six German engines and one Italian, were examined. Table IV summarises the investigations carried out on the gudgeon pins, while Table V similarly deals with wrist pins.

A.—GUDGEON PINS

Visual Examination

The surfaces of the pins were characterised by two or three well-defined brown circumferential markings, composed of a slight deposit—probably of carbon, with several less distinct rings between them (see Figs. 38 and 39). Owing to a shorter length of service the pins from the Mercedes-Benz D.B. 601A and D.B. 601N engines exhibited bright bands. The surfaces of the pins showed a well-lapped finish, which had become scratched in service.

With the exception of the pin from the Mercedes-Benz D.B. 601N engine (Report No. 91), all the pins showed eccentricity of the bore, which varied from one-half to seven-thousandths of an inch with respect to the external diameter. The dimensions are shown in Figs. 40 to 46.

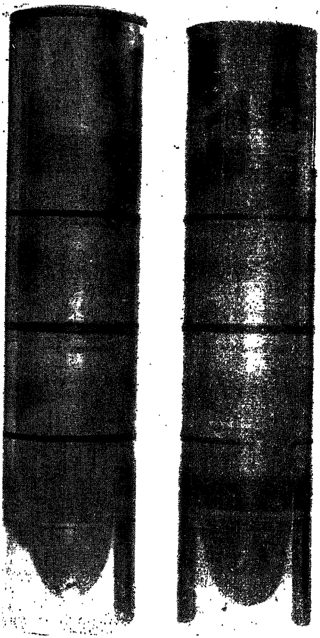


Fig. 38.—Gudgeon pins of Jumo 211A.

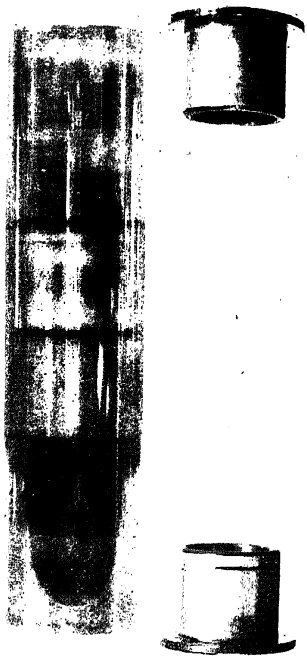


Fig. 39.—Gudgeon pin of Jumo 211F 1 (Engine 334).

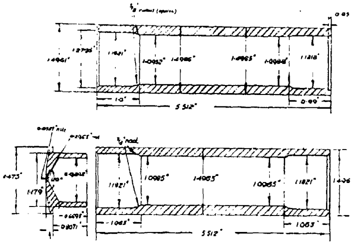
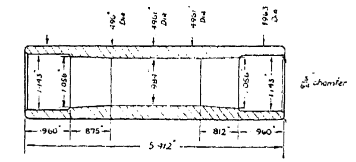


Fig. 40.—Jumo 211A gudgeon pins.



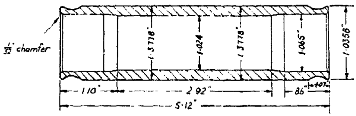


Fig. 43.—Bramo Fafnir 323P gudgeon pin.

Fig. 44.—Fiat A. 80R. C.41 gudgeon pin.

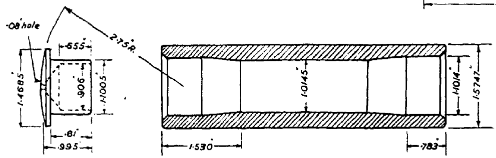


Fig. 41.—Jumo 211F 1 gudgeon pin (Engine 334).

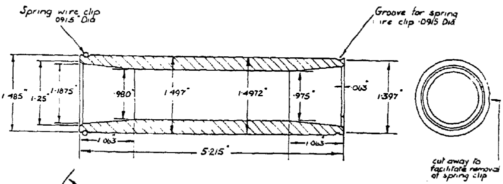


Fig. 42.—B.M.W. 132K gudgeon pin.

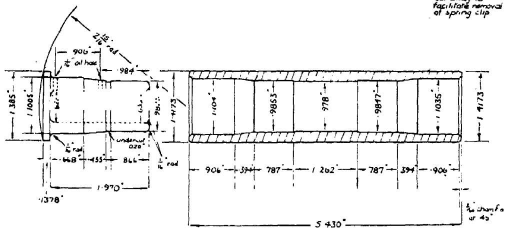


Fig. 45.—Mercedes-Benz D.B. 601A gudgeon pin.

Analysis

Six of the pins were made from carburising, three from nitriding, and one from direct-hardening steels. Three of the carburising steels contained 2% nickel, 2% chromium, ¼% molybdenum, and the other three contained 1% chromium, 0·2% molybdenum. Two of the nitrided pins were made from 2½% chromium-molybdenum steel, and the other from 1½% nickel, 1½% chromium, ¼% molybdenum, and 1% aluminium steel. The uniformly hardened steel contained 0·50% carbon, 1% chromium, and ½% molybdenum.

The low sulphur and phosphorus and comparatively high nitrogen contents indicate that all the steels were made by the basic electric-arc process.

Grain Size

The grain size of the steels from which the pins were produced varied from medium to fine.

Magnetic Etch Test

With the exception of the pin from

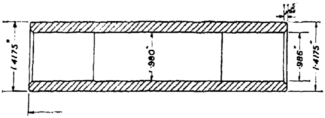


Fig. 46.—Mercedes-Benz D.B. 601N gudgeon pin.

the Bramo Fafnir 323P engine, all the pins were free from cracks or other defects which would be revealed by magnetic etching. The Bramo Fafnir pin, however, showed 15 longitudinal streaks associated with inclusions, the maximum length being 13/16 in.

Sulphur Prints

All the pins appeared to be free from segregation.

Macroscopical Examination

The macrostructure showed generally a well-defined uniform flow of metal, as typified by Fig. 47.

Hardness Tests

Diagrams and curves showing the surface and depth hardness of the pins are given in Figs. 48 to 59. The pin from the Italian Fiat A. 80R.C.41 engine showed a fairly uniform hard-

TABLE IV.—

Report No.	Type of Engine.	C.	Si.	Mn.	S.	P.	Ni	Cr.	Mo.	V.	Cu.	Al.
2	Jumo 211A—Pin No. 1 ...	0·155	0·30	0·44	0·008	0·012	2·10	2·21	0·225	Trace	—	0·010
	Pin No. 2 ...	0·16	0·20	0·44	0·010	0·014	2·18	2·07	0·24	Trace	—	0·010
117	Jumo 211.F.1 (Engine 334) No. 1...............	0·20	0·33	0·90	0·016	0·007	0·37	1·16	0·20	Trace	—	0·010
	No. 2...............	0·22	—	0·88	—	—	—	1·14	0·20	—	—	—
127	Jumo 211.F.1 (Engine 514)	0·19	0·28	0·46	0·016	0·016	1·96	1·91	0·24	—	—	0·007
16	B.M.W. 132K...........	0·25	0·38	0·58	0·006	0·009	0·10	2·58	0·21	0·08	0·105	0·006
23	Mercedes-Benz D.B. 601A	0·34	0·21	0·34	0·007	0·009	1·84	1·55	0·23	Nil	0·08	1·02
91	Mercedes-Benz D.B. 601N	0·28	0·27	0·59	0·010	0·009	0·28	2·77	0·22	0·15	0·15	0·005
43	Bramo Fafnir 323P......	0·21	0·25	0·93	0·010	0·012	0·26	1·12	0·25	Nil	0·115	Trace
78	Italian Fiat A. 80R.C.41 (B.R. 20 Aircraft).	0·50	0·295	0·65	0·013	0·014	0·12	1·10	0·20	Nil	—	0·013

TABLE V. -

Report No.	Type of Engine.	C.	Si.	Mn.	S.	P.	Ni.	Cr.	Mo.	V.	Cu.	Al.
14	B.M.W. 132K...........	0·27	0·42	0·67	0·005	0·006	0·15	2·51	0·19	Nil	0·08	- -
42	Bramo Fafnir 323P.....	0·31	0·33	0·84	0·004	0·005	0·26	2·73	0·24	Trace	0·09	- -
80	Italian Fiat A. 80R.C.41	0·52	0·275	0·63	0·008	0·009	0·05	1·01	0·16	0·03	Nil	0·009

ness of 550/571 V.P.N. throughout the section. The carburised pins showed fairly or very uniform surface hardness values, but the hardness of the nitrided samples decreased, or became irregular towards the ends. The hardness of the ends of the pins showed no consistent relationship to the case or bore hardness, and the results are summarised as follows :—

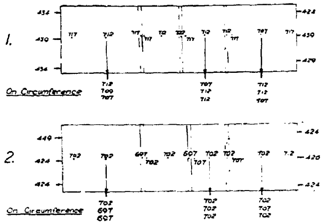


Fig. 48.—Vickers hardness tests, 30 kg. load, on Jumo 211A gudgeon pins.

Engine Type.	Hardness on End.
Junkers Jumo 211A (1)	Equal to core hardness.
Junkers Juno 211A (2)	Equal to core hardness.
Junkers Jumo 211.F.1 (Engine 334)	Equal to core hardness.
Junkers Jumo 211.F.1 (Engine 514)	Equal to case hardness.
B.M.W. 132K	Higher than case hardness of bearing surface.
Mercedes-Benz D.B. 601A	Very irregular.
Mercedes-Benz D.B. 601N	Generally lower and irregular.
Bramo Fafnir 323P	Lower than core hardness.

GUDGEON PINS.

W.	Ti.	Nitrogen.	Oxygen.	Surface Treatment.	Mechanical Properties (Core). M.S.	El. %.	R.A. %.	Diamond Hardness. Case.	Core.	Case Depth. In.	McQuaid Ehn Grain Size.
Nil	—	0·013 (0·023 (case)	0·0055	Carburised	—	—	—	700	425	0·043	8
Nil	—	0·014 (0·022 (case))	—	,,	—	—	—	700	425	0·038	8
—	—	0·015	—	Carburised	94·4	21·2	55·1	737—758	434	Outside 0·048	5—6
—	—	—	—	,,	—	—	—	,,	—	Inside 0·026	Mainly 5
—	—	0·014	—	Carburised	90·0	23·0	61·5	662—742	430	Outside 0·032 Inside 0·026	2—5 Mainly 4
Nil	Trace	0·012	—	Nitrided	81·0	19·0	60·0	800—900	380	Outside 0·016 Inside 0·017	5—6
Nil	Trace	0·012	0·008	Nitrided	78·5	23	58·8	900	370	0·021	5—6
Nil	—	0·009	0·008	Nitrided	80·0	21·2	63·5	774—876	370	Outside 0·022 Inside 0·015	5—6
Nil	0·01	0·012	0·0035	Carburised	91·9	19·0	59	700	410	0·028	2—6 Mainly 5
Nil	—	0·010	0·003	Uniformly hardened	—	—	—	550—571		—	3—5 Mainly 4

WRIST PINS.

W.	Ti.	Nitrogen.	Oxygen.	Surface Treatment.	Mechanical Properties (Core). M.S.	El. %.	R.A. %.	Diamond Hardness. Case.	Core.	Case Depth. In.	McQuaid Ehn Grain Size.
—	—	0·010	0·0016	Cyanided	—	—	—	869—876	383	0·02 to 0·03	5 to 6
—	—	0·010	0·0034	Nitrided	—	—	—	946—966	321—331	0·015	
Nil	Trace	0·012	0·003	Uniformly hardened	—	—	—				Mainly 5

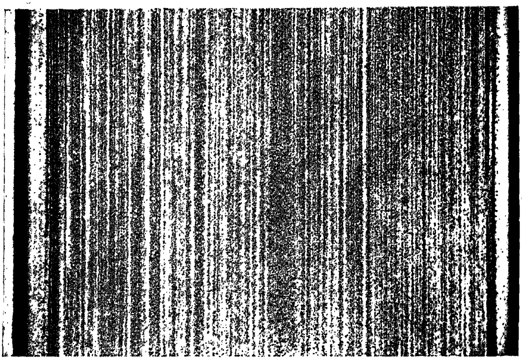


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Fig. 47.—Macro-structure of longitudinal section of B.M.W. 132K gudgeon pin. x 16.

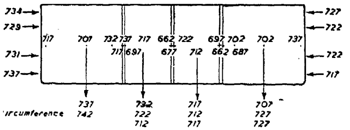


Fig. 49.—Vickers hardness tests, 30 kg. load, on a Jumo 211F 1 gudgeon pin.

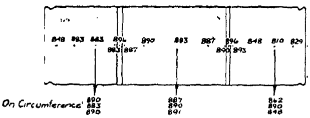


Fig. 50.—Vickers hardness tests, 30 kg. load, on a B.M.W. 132K gudgeon pin.

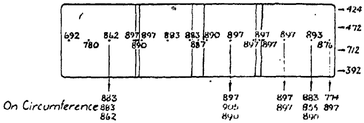


Fig. 51.—Vickers hardness tests, 30 kg. load, on a Mercedes-Benz D.B. 601A gudgeon pin.

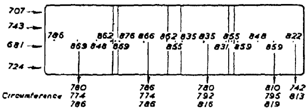


Fig. 52.—Vickers hardness tests, 30 kg. load, on a Mercedes-Benz D.B. 601N gudgeon pin.

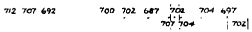


Fig. 53.—Vickers hardness tests, 30 kg. load on a Bramo Fafnir 323P gudgeon pin.

The hardness gradient across the case-hardened pins was fairly regular, but the hardness at the inner surfaces showed no consistent relationship to the outer case or core hardness. The results are summarised as follows :—

Engine.	Type of Case.	Hardness at Inner Surfaces.
Junkers Jumo 211.A (1)	Carburised	Increased towards bore.
Junkers Jumo 211A (2)	Carburised	Increased towards bore.
Junkers Jumo 211F.1 (Engine 334)	Carburised	Increased towards bore.
Junkers Jumo 211.F.1 (Engine 514) .	Carburised	Increased towards bore. Gradient similar to that at outer surface.
B.M.W. 132K	Nitrided	Increased towards bore. Gradient equal to that at outer surface.
Mercedes-Benz D.B. 601A	Nitrided	Slight decrease at bore surface.
Mercedes-Benz D.B. 601N	Nitrided	Marked increase at bore surface. Gradient steeper than that at outer surface.
Bramo Fafnir 323P	Carburised	Marked decrease at bore surf[illegible]

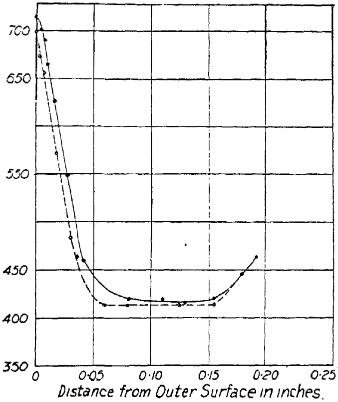


Fig. 54.—Depth-hardness curves of two Jumo 211A gudgeon pins.

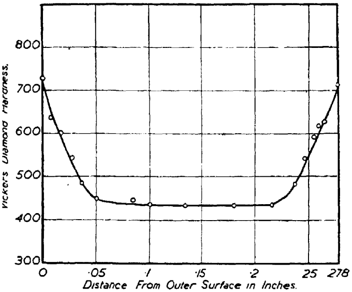


Fig. 55.—Depth-hardness curve of a Jumo 211F 1 (Engine 514) gudgeon pin.

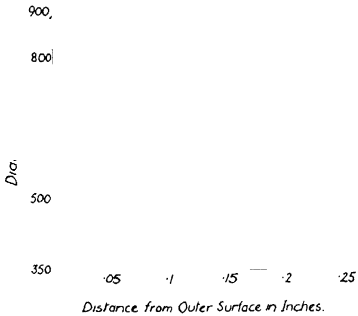


Fig. 56. Depth-hardness curve of a B.M.W. 132K gudgeon pin.

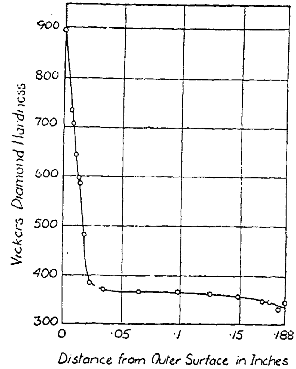


Fig. 57.—Depth-hardness curve of a Mercedes-Benz D.B. 601A gudgeon pin.

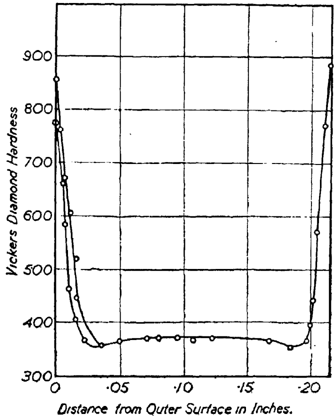


Fig. 58.—Depth-hardness curve of a Mercedes-Benz D.B. 601N gudgeon pin.

Microscopical Examination

(*a*) *Cleanness.*—None of the steels from which the pins was manufactured were equal to the British standard of cleanness in steels used for this particular component. The main types of inclusions consisted of sulphides and silicate streaks up to 0·020 in. in length, but in the pin from the Bramo Fafnir 323P engine inclusion streaks up to $\frac{13}{16}$ in. were found.

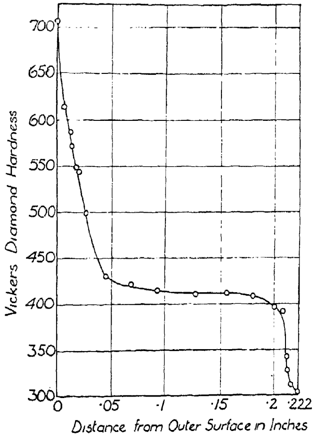


Fig. 59.—Depth-hardness curve of Bramo Fafnir 323P gudgeon pin.

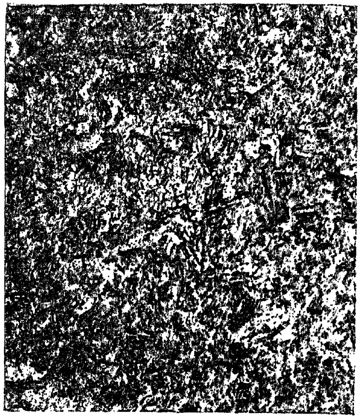


Fig. 60.—Core structure of Jumo 211A gudgeon pin. x 300.

(*b*) *Microstructure.* — The following observations were made :—

Figs. 60 and 61 illustrate the structures of two of the pins examined.

Engine.	Structure.
Junkers Jumo 211A ; Junkers Jumo 211.F.1 (Engine 514)	Fine martensitic case with some free carbide. Core slightly coarse and acicular.
Junkers Jumo 211.F.1 (Engine 334)	Similar to above but no free carbide in case.
B.M.W. 132K	Case fairly coarse acicular structure with marked nitride and carbide network. Core, fine sorbite.
Mercedes-Benz D.B. 601A	Case showed coarse acicular structure with marked carbide and nitride network. Case brittle. Core, fine sorbite.
Mercedes-Benz D.B. 601N	Similar to D.B. 601A but carbide and nitride network only slight.
Bramo Fafnir 323P	Generally fine structure with some free carbide. Inner face markedly decarburised.
Italian Fiat A. 80R.C.41	Slightly banded structure; dense sorbite having mottled appearance.

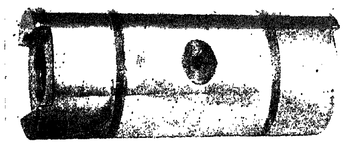


Fig. 62.—Wrist pin of Bramo Fafnir 323P.

B.—WRIST PINS

Only three wrist pins were examined, one from a B.M.W. 132K engine, one from a Bramo Fafnir 323 type, and a third from the Italian Fiat A. 80R.C.41 engine. The results are summarised in Table V.

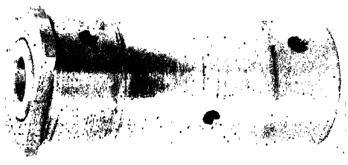


Fig. 63.—Wrist pin of Fiat A. 80R.C.41.

Appearance

The surface finish of each showed a smooth lapped appearance, whilst on the non-bearing surfaces of the German pins there was a dark-brown deposit.

Fig. 61.—Structure of Mercedes-Benz D.B. 601N gudgeon pin.

Two examples are illustrated in Figs. 62 and 63.

Analyses

The German pins were made from $2\frac{1}{2}\%$ chromium-molybdenum steel, and the Italian was of 1% chromium-molybdenum.

Hardness

The high surface hardness of the German pins indicated a case-hardening treatment, and this was confirmed by later examination. Figs. 64 and 65 show the surface and depth hardness characteristics of each type. The Italian pin, however, had been made from a direct hardening steel with no surface treatment, and was of uniform hardness throughout—i.e., 550/570 D.H.

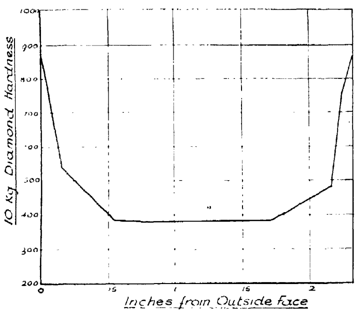


Fig. 64. Diamond hardness across section of wrist pin of B.M.W. 132K.

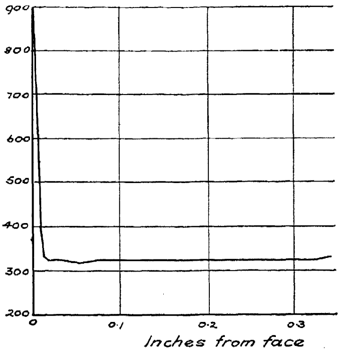


Fig. 65.—Diamond hardness across section of wrist pin of Bramo Fafnir 323P.

Sulphur Print and Macro Examination

As was to be expected from the sulphur contents of the steel—viz., 0·004 and 0·005% for the B.M.W. 132K and Bramo Fafnir 323P engines, respectively, and 0·008% for the Fiat A. 80R.C.41,—the sulphur prints on a longitudinal section of each showed very little in the way of sulphide markings. Macro-examination presented no unusual features.

Microscopical Examination and Grain Size

The following inclusion counts (Fox method) were recorded on the German pins :—

B.M.W. 132K	38
Bramo Fafnir 323P	33

In all the steels examined the cleanness was below British Standards. The core structures were sorbitic in all three instances.

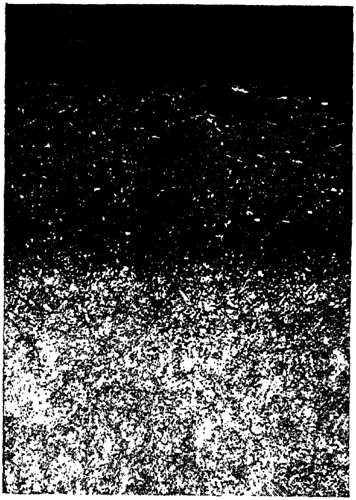
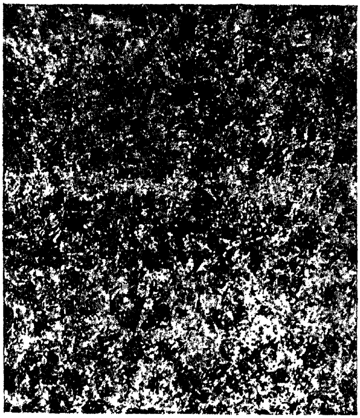


Fig. 66.—Structure of B.M.W. 132K wrist pin. x 100.

Fig. 67.—Structure of Bramo Fafnir wrist pin. x 100.



Examination near the surface of the German pins confirmed that case hardening has been carried out, but showed that whilst the B.M.W. 132K pin had been subjected to a cyaniding treatment the other pin (Bramo Fafnir 323P) had been nitrided. The former was cyanided both on the outside and the core, but the Bramo Fafnir 323P pin was nitrided on the outer surface only. The B.M.W. 132K presented a reasonably fine structure with a rather prominent network on the core case, whilst in the Bramo Fafnir 323P the structure of the case was generally uniform. (Figs. 66 to 68.)

Fig. 68.—Structure of Fiat A. 80R.C.41 wrist pin. x 300.

Section V—Cylinders and Cylinder Liners

THE aero-engine cylinder and cylinder liners examined classified as follows:—

Liquid Cooled

Report No. 3—Junkers Jumo 211A (see Fig. 69).
,, 97—Jumo 211H (see Fig. 70).
,, 116—Jumo 211.F.1.
,, 125—Jumo 211.F.1.
,, 48—Mercedes-Benz D.B. 601A (see Fig. 71).

Air Cooled

Report No. 12—B.M.W. 132K (see Fig. 72).
,, 45—Bramo Fafnir 323P.
,, 79—Fiat A. 80R.C.41 (see Fig. 73).
,, 133—B.M.W. 801A1.

With the exception of the Italian cylinder (Report No. 79) all were of German manufacture.

The machining of the cylinders was good, and the bore surfaces had been finely finished, probably honed; only two of the samples, the Jumo 211A cylinder (Report No. 3) and the Mercedes-Benz D.B.601A (Report No. 48), showed any pronounced scoring.

The Italian Fiat A. 80R.C.41 cylinder was 0·50 carbon steel, but the German cylinders and liners had been made from a $1\frac{1}{2}$% chromium steel, with the exception of B.M.W. 132K (Report No. 12), which consisted of a 1% chromium steel with low molybdenum. In all the other steels the presence of molybdenum and nickel appeared to be accidental.

The sulphur and phosphorus contents of the Fiat cylinder were 0·034% and 0·017% respectively, and this steel had evidently been made by the open-hearth process. The cleanness was only reasonably satisfactory, and a Fox count of 107 was obtained. A micrograph is shown in Fig. 74.

The sulphur and phosphorus contents of the German cylinders and liners ranged from 0·005% to a maximum of 0·031%, but even so it seemed likely that these steels were made in the basic electric furnace. They were classed as clean to reasonably clean, and a typical micrograph is shown in Fig. 75.

Hardness and Tensile Strength

All the cylinders were of uniform hardness with no surface hardening of the bore. Tensile tests were taken from some samples, and from others the equivalent strength was determined from the hardness figures. The B.M.W. 132K cylinder (Report No. 12) gave a tensile strength of 67·6 tons per sq. in.,

TABLE VI.—CHEMICAL ANALYSES.

No.		C, %.	Ni, %.	Cr. %.	Mo, %.
	LIQUID COOLED.				
3	Jumo 211A	0·44	0·18	1·46	0·08
97	Jumo 211H	0·40	0·05	1·43	0·03
116	Jumo 211.F.I	0·47	0·02	1·49	0·02
125	Jumo 211.F.I	0·49	0·05	1·49	Nil
48	Mercedes-Benz D.B. 601A	0·45	0·09	1·52	Nil
	AIR COOLED.				
12	B.M.W. 132K	0·38	0·27	1·03	0·13
45	Bramo Fafnir 323P	0·45	0·08	1·46	0·03
79	Fiat A. 80R.C.41	0·50	0·19	0·12	Nil
133	B.M.W. 801A1	0·45	0·09	1·50	0·07

with an elongation of 20%, but with this exception, the tensile strengths of all the other cylinders fell within a range of 48—55 tons per sq. in. (See Table VII.)

Method of Manufacture

The macrostructures indicated that the Jumo 211A cylinder (Report No. 3) and the B.M.W. 132K cylinder (Report No. 12) had been made as punched forgings, but the remainder appeared to have been in the form of tubes.

The Italian Fiat A. 80R.C.41 cylinder had evidently been made from a comparatively large ingot but a small ingot appeared to have been used for the German liners and cylinders.

Heat-Treatment and Microstructure

All the cylinders and liners had been hardened and tempered at normal temperatures producing fine-grained microstructures.

The 0·50% carbon steel Fiat cylinder possessed a microstructure consisting of

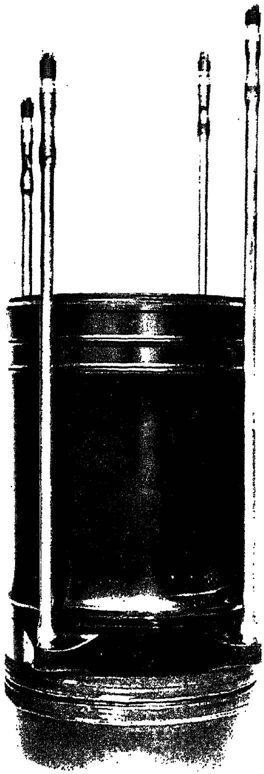


Fig. 69.—Junkers Jumo 211A.

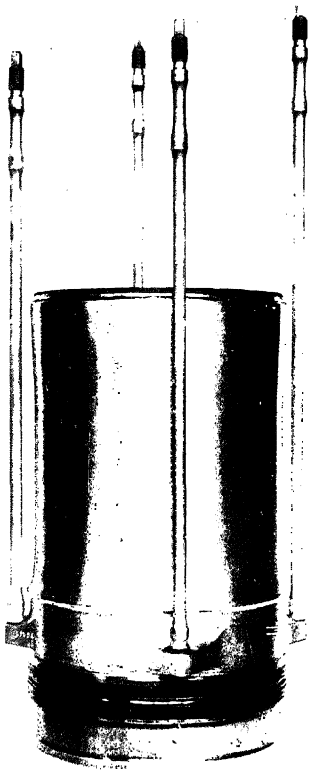


Fig. 70.—Junkers Jumo 211H.

sorbite grains outlined by a ferrite network (see the micrograph Fig. 76), but the structures of the remaining cylinders were wholly sorbitic. (See Fig. 77.)

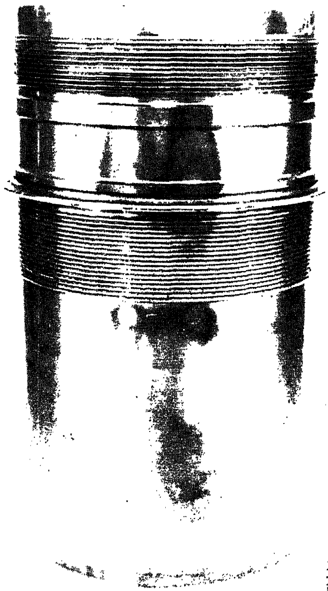


Fig. 71. Mercedes-Benz D.B. 601A.

Differences in Design and Manufacture

A comparison of Fig. 69 with Fig. 70 shows that the Jumo liner 211A (Report No. 3) had been enamelled in black. All the subsequent liners were chromium-plated and this plating had been done on a smooth-ground surface, with no further preparation after plating.

The Jumo 211A liner (Report No. 3, see Fig. 69) had parallel sides, but the sides of all the other liners were tapered (Fig. 70).

The wall thickness of the cylinders and liners was determined as shown on page 41.

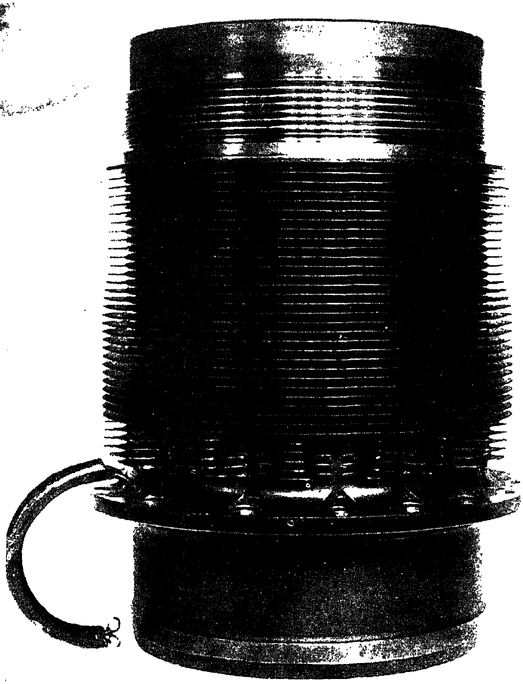
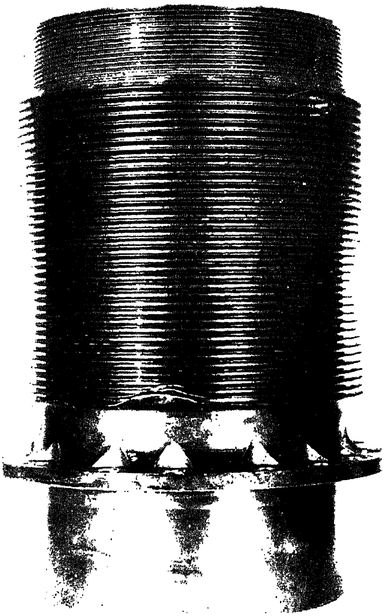


Fig. 72. B.M.W. 132K.



The variation in the thickness of the wall of the air-cooled cylinders was an intentional thickening at about one-third of the length below the head.

The depth of the fins of the air-cooled cylinders varied as follows :—

			Depth of Fins.
Report No.	12	B.M.W. 132K	0·45 in.
,,	45	Bramo Fafnir 323P	0·72 in.
,,	79	Fiat A. 80R.C.41	0·35 in.
,,	133	B.M.W. 801A1	0·66 in.

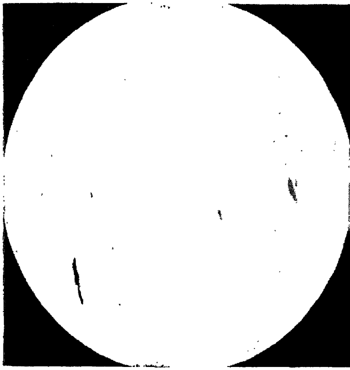
The fins on the Fiat cylinder were unusually shallow.

Reference to Fig. 72, a photograph of the cylinder from the B.M.W. 132K engine (Report No. 12) shows a thermocouple attached to the flange. The two wires consisted of iron and constantan (copper, 54% ; nickel, 42%), and

Fig. 73.—Fiat A. 80R.C.41.

TABLE VII.—MECHANICAL PROPERTIES.

Report No.	Type of Engine.	Component.	Grain Size.	Y.P., Tons/sq. in.	M.S., Tons/sq. in.	El., %.	R./A., %.	Izod, Ft.-lbs.	Diamond Hardness.
3	Junkers Jumo 211A	Cylinder liner	4—7	—	52·0 approx.	—	—	—	—
		Cylinder bolt	6	60·0	66·7	22·5	66·6	70	—
97	Junkers Jumo 211H	Cylinder liner	6	37·8	47·8	27·5	61·5	—	—
		Liner bolts	—	—	67·1	24·4	63·8	75	324 (3 bolts)
116	Junkers Jumo 211.F.1	Cylinder liners :							
		D.B.E. 1	—	—	—	—	—	—	236/240
		S.B.E. 2	—	—	—	—	—	—	260/265
		Cylinder bolts :							
		D.B.E. 1	—	—	—	—	—	—	337
		S.B.E. 2	—	—	—	—	—	—	334
125	Ditto	Cylinder liner	—	—	—	—	—	—	273/279
48	Mercedes-Benz D.B. 601A	Cylinder liner	Mainly 4—6 with a few coarser grains.	46·5	54·2	28·0	—	—	—
12	B.M.W. 132K	Cylinder	5	—	67·6	20·0	50·2	—	—
45	Bramo Fafnir 323P	Cylinder	4—6	—	51·0	22·5	52·2	—	—
79	Fiat A. 80R.C. 41	Cylinder barrel	3—4	—	51·7	26·0	34·3	—	—
133	B.M.W. 801A/1	Cylinder barrel	6—7	45·5	53·7	25·0	33·4	—	—



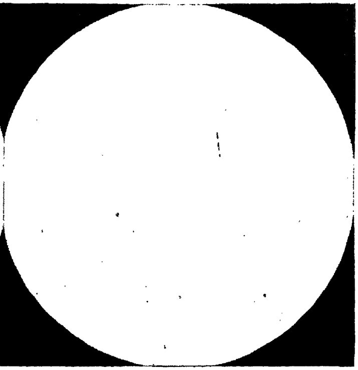
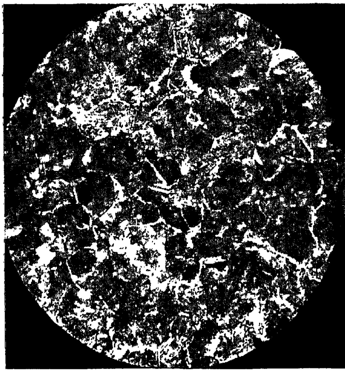


Fig. 74.—Typical micrograph of Fiat cylinder, showing degree of cleanness. x 100.

Fig. 75.—Typical micrograph of German cylinders and liners, showing degree of cleanness. x 100.



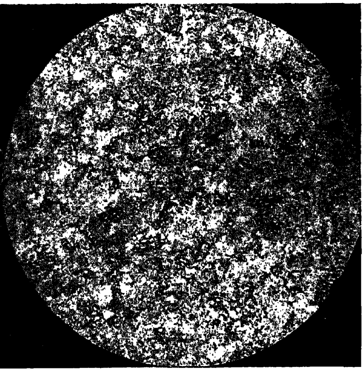


Fig. 76.—Structure of Fiat cylinder. x 100.

Fig. 77.—Sorbitic structure of remaining cylinders. x 100.

the method of attaching them to the cylinder is shown in Figs. 78 and 79. It was apparent that the wires had been brazed into a small brass plug, which was then put at the bottom of the drilled hole and held in by a copper sleeve.

Cylinder Head Bolts

The cylinders shown in Figs. 69 and 70 were complete with head bolts.

Report No.	Liquid Cooled.	Wall Thickness.
	Jumo 211.A	Uniform 0·10 in.
	Jumo 211H	Tapered to 0·08 in. min.
116	Jumo 211.F.1	Tapered to 0·1 in. min.
125	Jumo 211.F.1	Tapered to 0·1 in. min.
	Mercedes-Benz D.B. 601A	Uniform 0·10 in.
	Air Cooled.	
12	B.M.W. 132K	Uniform 0·15 in.
45	Bramo Fafnir 323P	Uniform 0·10 in.
79	Fiat A. 80R.C.41	Variable 0·10 in. to 0·13 in.
133	B.M.W. 801A1	Variable 0·12 in. to 0·16 in.

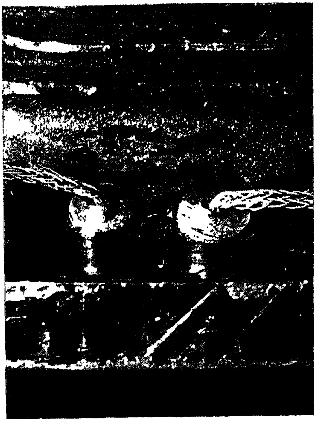


Fig. 78.—Method of attaching thermocouple to cylinder shown in Fig. 4. x 2.

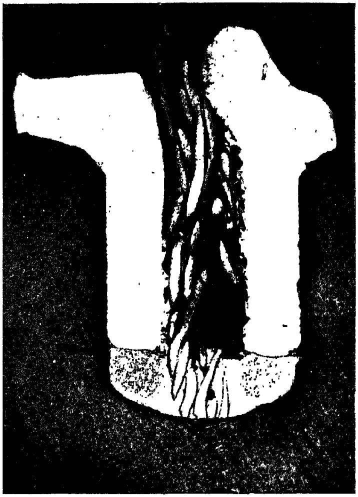


Fig. 79.—Section showing method of attaching thermocouple to cylinder. x 10.

Those on the Jumo 211A and 211F 1 cylinders had been made from 2% nickel, 2% chromium-molybdenum steel, heat-treated to a tensile strength of 66/68 tons per sq. in.; but the bolts on the Jumo 211H liner (Report No. 97) had been made from a 1% chromium-molybdenum steel, heat-treated to a similar tensile strength, and in this way a considerable economy of alloys had been effected without any sacrifice of mechanical properties.

The threads only of the Jumo 211A bolts, examined under Report No. 3, had been plated, but the Jumo 211H bolts (Report No. 97) had been plated throughout with cadmium, and the Jumo 211.F.1 bolts with chromium.

Section VI—Inlet and Exhaust Valves

THE following valves were examined:

Two inlet valves and two exhaust valves taken from a Junkers Jumo 211A engine (Report No. 6).

An inlet and two exhaust valves taken from a B.M.W. 132K aero engine (Reports Nos. 15 and 27).

An inlet and an exhaust valve taken from a Mercedes-Benz D.B. 601A aero engine (Report No. 22).

An inlet and an exhaust valve taken from a Bramo Fafnir 323P aero engine (Report No. 46).

An inlet and an exhaust valve taken from a Mercedes-Benz D.B. 601N aero engine (Report No. 89).

An inlet and an exhaust valve taken from a Fiat A. 80R.C.41 aero engine (Report No. 76).

A summary of the essential data is given in Table VIII.

Chemical Composition

The two inlet valves from the Junkers Jumo engine were made from a high-carbon stainless steel, but all the others had been manufactured from silicon-chromium steel equivalent to British Specification D.T.D. 13B. Without exception the exhaust valves were made from steel to D.T.D. 49B type. All the valves had undoubtedly been made by the basic electric-arc process, and in many instances small titanium and zirconium additions were found. Evidence to the effect that lead-doped fuel had been used was found in the presence of lead in the oxides on all the valve heads. (See Table I).

Constructional Details

Inlet Valves.—All the inlet valves taken from the Junkers Jumo 211A, the B.M.W. 132K and the Fiat A. 80 R.C.41 engines were solid, whilst those from the Mercedes-Benz D.B. 601A, the Mercedes-Benz D.B. 601N and Bramo Fafnir 323P engines were hollow, and had no sodium coolant. On the other hand, all the exhaust valves were hollow, the cavities in some instances running into the heads, and all contained sodium coolant. In the solid inlet valves the tappet ends were locally hardened, except in the Fiat engine, where Stellite type carbide had been deposited. The hollow stems were sealed by local forging and a hard deposit of Stellite-type carbide. Only in the single instance of the inlet valve from the Bramo Fafnir engine had local forging and hardening been carried out, thus leaving a fine duct which outcropped on to the tappet end of the valve. (Fig. 80, A to F).

Exhaust Valves.—Greater variation in design was found among the exhaust valves. Exhaust valves from the Junkers Jumo 211A and D.B. 601N engines had been drilled hollow through the head and sealed with a plug of similar material, whilst those from the B.M.W. 132 K engines had been machined hollow in the head and stem and a cap of similar material welded on to the head and a plug of similar material sealed with Stellite-type carbide into the stem at the tappet end. The exhaust valve from the Mercedes-Benz D.B. 601A engine had a drilled hollow stem plugged at the tappet end with steel of similar material and also sealed with Stellite-type carbide. The exhaust valve from the Bramo Fafnir engine was similar except that the head was partially hollow, this being effected by first drilling the stem and then hot upsetting the head. The exhaust valve from the Fiat A. 80R.C.41 aero engine was similar to other hollow-stemmed

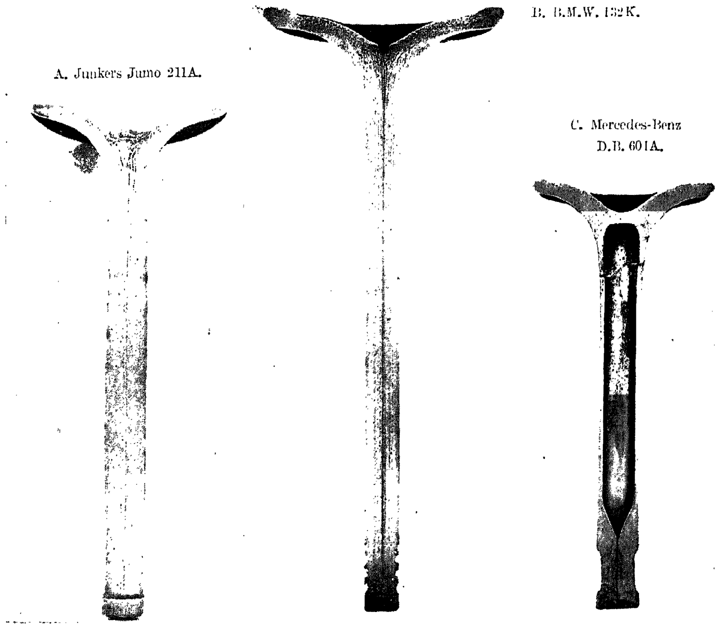


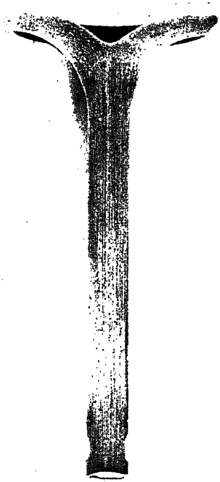
Fig. 80.—Inlet Valves.

TABLE VIII.—VALVES CHEMICAL

Report No.	Type of Engine.	Type of Valve.	C.	Si.	Mn.	S.	P.
6	Jumo 211A	Inlet 1	1·65	0·19	0·38	0·010	0·020
		,, 2	1·64	0·42	0·14	0·008	0·014
		Exhaust 1	0·42	1·12	1·35	0·027	0·015
		,, 2	0·50	1·45	0·77	0·010	0·016
15	B.M.W. 132K......	Inlet	0·51	2·76	0·35	0·009	0·015
		Exhaust	0·49	1·54	0·55	0·011	0·020
27	B.M.W. 132K......	Exhaust	0·55	1·80	0·71	0·009	0·009
22	Mercedes-Benz D.B. 601A	Inlet	0·45	2·82	0·49	0·016	0·016
		Exhaust	0·51	1·61	0·69	0·016	0·014
89	Mercedes-Benz D.B. 601N	Inlet	0·37	2·90	0·32	0·027	0·013
		Exhaust	0·46	1·60	0·67	0·008	0·014
46	Bramo Fafnir 323P	Inlet	0·40	2·60	0·31	0·016	0·019
		Exhaust	0·46	1·10	0·85	0·022	0·019
76	Italian Fiat A. 80 R.C. 41	Inlet	0·41	2·58	0·38	0·024	0·028
		Exhaust	0·51	1·00	0·87	0·008	0·019

D. Bramo Fafnir 323P.

F. Fiat A. 80R.C.41



E. Mercedes-Benz D.B. 601N.

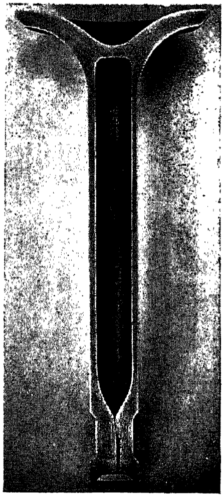
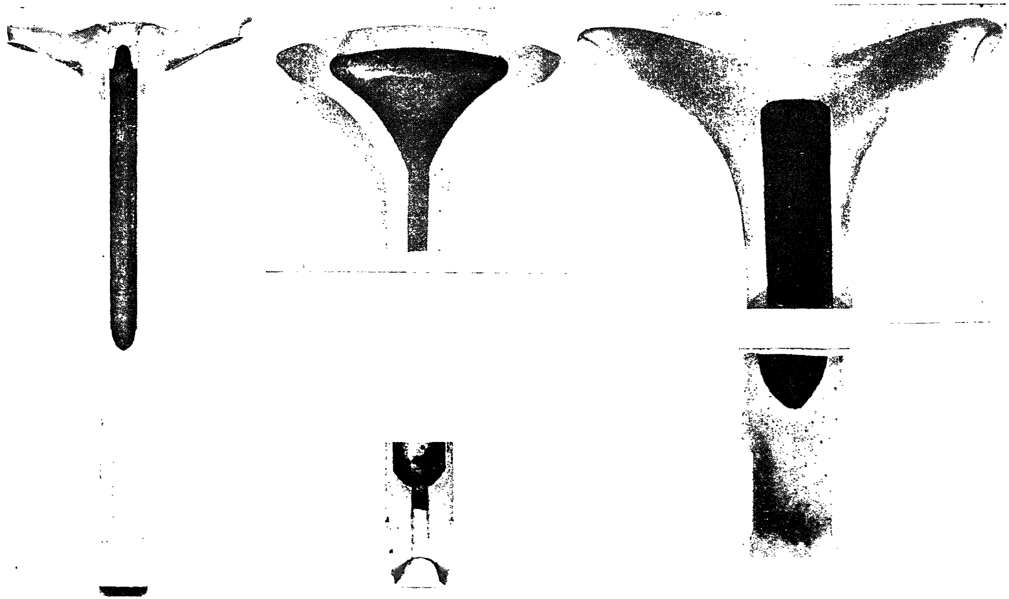


Fig. 80.—Inlet Valves.

COMPOSITION AND HARDNESS VALUES.

Ni.	Cr.	Mo.	V.	Cu.	Al.	W.	Hardness.
0·27	11·7	Nil	Nil	0·05	0·04	Nil	263/336
0·16	12·3	Nil	Nil	—	0·02	0·12	—
13·0	13·0	0·12	Nil	—	0·02	2·81	215/235
13·9	14·5	0·05	Nil	0·06	—	2·38	—
Nil	11·2	$<$0·05	—	0·09	0·033	Nil	281/306
13·3	15·0	Nil	—	0·043	—	2·38	203/297
13·2	15·5	Nil	Nil	0·08	0·015	2·02	256/274
—	9·07	0·08	—	0·06	—	—	276/289
12·8	13·6	$<$0·05	—	0·016	—	2·2	249/276
—	10·8	Nil	Nil	0·10	—	—	262/306
13·6	15·4	Nil	0·02	0·08	0·028	2·61	224/243
0·20	11·20	0·04	0·02	0·090	0·022	Nil	254/271
12·90	14·40	0·13	Nil	0·070	—	2·30	223/271
—	8·40	0·16	—	0·046	—	—	360/380
13·8	12·8	0·80	—	—	0·036	2·96	222/254



G. Junkers Jumo 211A. H. B.M.W. 132K. I. Mercedes-Benz D.B. 601A.

Fig. 81.—Exhaust Valves.

valves drilled from the tappet end, except that a hollow plug had been inserted towards the lower portion of the stem to prevent too much heat reaching the springs from the sodium coolant. Around the seats of all the exhaust valves Stellite-type carbide metal had been effectively deposited, but no such deposit had been made

Macrostructure

The grain flow of the heads of the inlet and exhaust valves was typical of a hot-heading operation. Pronounced structural alteration was noted in the stem of the exhaust valve from the Mercedes-Benz D.B. 601A engine. A high degree of cleanness was noted throughout the examination of these valves.

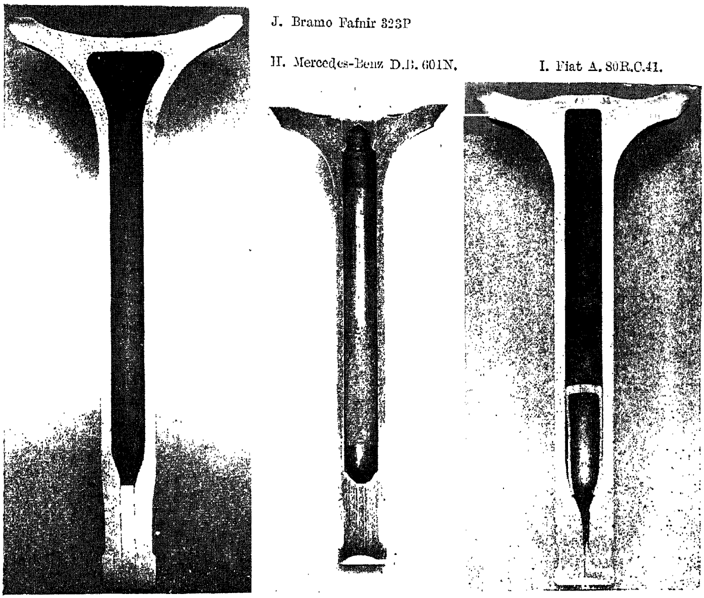


Fig. 81.—Exhaust Valves.

around the seats of the inlet valves. (Fig. 81, G to L.)

Hardness Tests

The hardness values of all the valves were normal for the structural condition; they were approximately 250/320 V.D.H. for the inlet valves and 220/270 for the exhaust valves. None of the valves had been nitrided.

Microstructure

All the inlet valves had typically hardened and tempered structures. On the other hand, the general structure of the exhaust valves was austenitic, although almost without exception various degrees of a duplex structure were present, the amount of this structure being directly proportional to the measure of cold work put on to the steel

towards the end of the forging operation. An effective junction had been made with the base metal wherever Stellite-type material had been deposited.

Remarks

The inlet and exhaust valves had been made from high-quality steels and showed a high standard of workmanship. They obviously met the design requirements of the engines in which they normally worked. None of the exhaust valves can be directly compared with British aero-engine valves as these are required to work at higher operating temperatures and in the presence of lead-oxide concentrations which necessitate covering the entire head of the valve with an 80 : 20 nickel-chromium alloy. As far as can be judged the enemy exhaust valves compare generally with British exhaust valve practice, whereas the enemy inlet valves are apparently less efficient, probably due to inferior fuel, etc., and would be considered very inadequate by our present standards. No evidence was found to justify the view that shortage of raw materials had influenced alloy content or steel quality.

Section VII—Valve Springs

THE results of the examination of 34 inner and outer inlet and exhaust valve springs from eight German and Italian aero engines are given in Table IX. The table also includes data from Messrs. Brunton's (Musselburgh) Ltd. on eight valve springs from four types of engines. These can be identified by the letters B.M. in the report column. Representative photographs of typical springs are shown in Fig. 82 (Bramo Fafnir 323P, Report No. 18), and Fig. 83 (Mercedes-Benz D.B. 601A, Report No. 18) respectively.

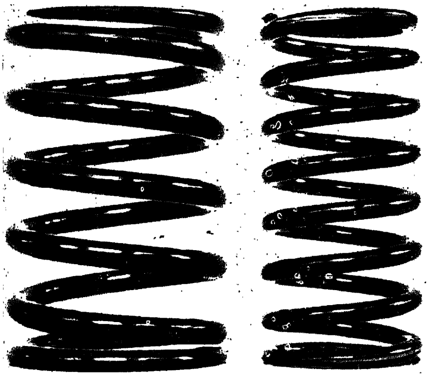


Fig. 82.—Bramo Fafnir 323P.

Visual Examination

The surfaces of the springs had been either shot or sand blasted, and showed temper colours. Most of the surfaces had a coating of lacquer, and only in the case of the German B.M.W. (Type 132K) inlet and valve springs was a metallic coating applied, this being of cadmium. Under visual examination none of the springs showed draw marks (see macro-examination).

Dimensions

The dimensions and details of the springs are given in Tables X and XI, and a key to the dimensions is shown in Fig. 84. The springs from the two types of Mercedes-Benz engine were conical wound, the remainder being cylindrical.

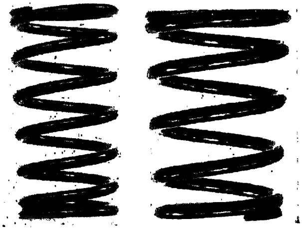


Fig. 83.—Mercedes-Benz D.B. 601A.

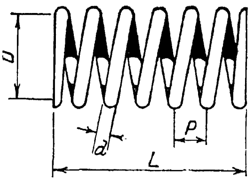


Fig. 84.—Dimension calculations.

Solid height = (Total number of coils — $\frac{1}{2}$)d.
No. of active coils = Total No. of coils tip to tip — $1\frac{1}{2}$
Length of wire = $D \times \pi \times$ No. of coils = $D \times \pi \times n$
Total deflection = Free height — solid height.
Where d = diameter of wire.
D = Mean diameter of coil at the centre of the spring.

Analysis

The springs from the Italian Fiat A. 80R.C. 41 engine were made from a 0·50/0·55% carbon, 1% chromium, ¼% vanadium steel, the remainder, with the exception of the Jumo 211F 1 springs, being of plain 0·60/0·70% carbon steel. It will be noted that these Jumo 211F 1 springs are of a silicon-chromium steel, which constitutes a

marked departure from previous practice. All are commendably low in sulphur and phosphorus, except the already mentioned Jumo 211F 1 springs. These have a rather higher sulphur content than the others.

Method of Manufacture of Steel

The analyses of the steels indicate that they are made by the basic electric arc, or possibly the Swedish open-hearth process. The Jumo 211F 1 springs showed a distinctly higher

TABLE IX.—VALVE SPRINGS. CHEMICAL COMPOSITION.

Report No.	Type of Engine.	C.	Si.	Mn.	S.	P.	Ni.	Cr.	Mo.	V.	Cu.	W
18	German Jumo 211A.											
	Outer	0·68	0·125	0·47	0·010	0·025	Trace	0·025	Nil	Nil	Nil	—
	Inner	0·70	0·14	0·53	—	—	Trace	<0·005	Nil	Nil	Nil	—
B.M.1	German Jumo 211D.											
	Outer	—	—	—	—	—	—	—	—	—	—	—
	Inner	0·70	0·15	0·58	0·019	0·027	Trace	Trace	Nil	Nil	—	Nil
119	German Jumo 211.F.1.											
	Inlet—Outer	0·61	1·40	0·73	0·030	0·016	0·05	0·70	Nil	Nil	0·09	—
	Inner	0·62	1·47	0·72	0·021	0·016	0·03	0·69	Nil	Nil	0·09	—
	Exhaust—Outer	0·61	1·38	0·73	0·030	0·015	0·04	0·70	Nil	Nil	0·09	—
	Inner	0·62	1·47	0·72	0·022	0·016	0·03	0·70	Nil	Nil	0 09	—
18	German B.M.W. 132K.											
	Inlet—Outer	0·67	0·17	0·48	0·007	0·021	Trace	0·005	Nil	Nil	Nil	—
	Inner	0·63	0·14	0·54	0·007	0·022	Trace	0·015	Nil	Nil	Nil	—
	Exhaust—Outer	0·67	0·145	0·46	0·008	0·022	Trace	0·015	Nil	Nil	Trace	—
	Inner	0·67	0·13	0·50	0·012	0·022	Trace	0·010	Nil	Nil	Nil	—
18	Mercedes-Benz D.B. 601A.											
	Outer	0·68	0·17	0·48	0·007	0·022	Trace	<0·005	Nil	Nil	Nil	—
	Inner	0·65	0·17	0·53	—	—	Trace	0·020	Nil	Nil	Nil	—
B.M.2	Mercedes-Benz D.B. 601A.											
	Outer	0·70	0·16	0·62	0·024	0·024	Nil	Trace	Nil	Trace	—	Nil
	Inner	—	—	—	—	—	—	—	—	—	—	—
B.M.3	Mercedes-Benz D.B.601N.											
	Outer	—	—	—	—	—	—	—	—	—	—	—
	Inner	0·68	0·17	0·72	0·014	0·020	Nil	0·22	Nil	Trace	—	Nil
90	Mercedes-Benz D.B.601N.											
	Inlet—Outer	0·69	0·19	0·60	0·014	0·008	Trace	0·08	Trace	Trace	0·075	--
	Inner	0·67	—	0·54	0·009	0·017	Trace	Trace	Trace	Trace	0·01	--
	Exhaust—Outer	0·63	0·19	0·53	0·011	0·022	Trace	Trace	Trace	Trace	0·01	—
	Inner	0·69	—	0·49	0·016	0·012	Trace	Trace	Trace	Trace	0·05	--
18	German Bramo Fafnir 323P.											
	Outer	0·64	0·185	0·54	0·007	0·020	Trace	<0·005	Nil	Nil	Nil	—
	Inner	0·63	0·17	0·49	0·005	0·021	Trace	<0·005	Nil	Nil	Nil	—
B.M.4	German Bramo Fafnir 323P.											
	Outer	0·67	0·18	0·72	0·012	0·020	Nil	Trace	Nil	Trace	—	Nil
	Inner	—	—	—	—	—	—	—	—	—	—	—
47	German Bramo Fafnir 323P.											
	Inlet—Outer	0·66	0·20	0·61	0·011	0·023	Trace	Trace	Trace	Trace	Nil	—
	Inner	0·65	0·14	0·50	0·010	0·022	Trace	Trace	Trace	Trace	Nil	—
	Exhaust—Outer	0·65	0·20	0·62	0·012	0·024	Trace	Trace	Trace	Trace	Nil	—
	Inner	0·65	0·19	0·62	0·011	0·022	Trace	Trace	Trace	Trace	Nil	—
77	Italian Fiat A. 80R.C.41.											
	Inlet—Outer	0·54	0·30	0·64	0·022	0·016	0·09	0·98	Trace	0·25	0·12	—
	Inner	0·50	0·21	0·61	0·012	0·023	0·07	0·94	Trace	0·24	0·12	—
	Exhaust—Outer	0·54	0·29	0·64	0·019	0·017	0·08	0·96	Trace	0·27	0·11	—
	Inner	0·50	0·22	0·58	0·014	0·023	0·07	0·93	Trace	0·23	0·145	—

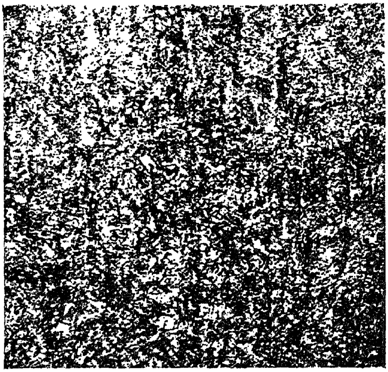
nitrogen content than the remainder of the springs, which might be explained by postulating a high nitrogen base (Bessemer scrap) and the absence of a vigorous boil in refining.

Grain Size

The inherent grain size of all the spring steels was coarse, with the one exception of the Jumo 211.F.1 engine, in which the grain size was medium to fine.

HARDNESS VALUES, AND RESULTS OF VISUAL EXAMINATION.

N.2.	Diamond Hardness.	McQuaid/Ehn Grain Size.	Exterior Examination.		Clean-ness.
			Coating.	Surface Finish.	
0·004 0·004	445 391	1 to 4 (Mainly 3) 1 to 3 (Mainly 2)	Carbonaceous deposit. "	Sand-blasted, bluish temper colour.	Fair. "
— —	424 426	— —	— —	— —	Good "
0·016 0·0135 0·0165 0·0125	490 510 495 480	3 to 5 (Mainly 4) 3 to 5 (Mainly 4 to 5) 4 to 6 (Mainly 4 to 5) 4 to 5	Dark golden-brown lacquer. " " "	Sand-blasted. " " "	Fair. " " "
0·0045 0·0050 0·0045 0·0035	421 437 444 444	2 to 4 (Mainly 3) " " "	Bright coating of cadmium. " Dull black carbonaceous coating over bright coating of cadmium.	Finely ground Sand-blasted. " "	Fair " " " "
0·005 —	455 460	2 to 4 (Mainly 3) 1 to 4 (Mainly 3)	Dull brownish coating of carbonaceous matter over coating of golden-brown lacquer.	Sand-blasted and marked temper colouring. "	Fair. "
— —	430 427	— —	— —	Light shot-blasted finish, cross-grinding marks. Shot-blasted finish.	Good. "
— —	434 437	— —	— —	Possibly shot-blasted. Probably shot-blasted.	Good "
0·006 0·005 0·006 0·0065	435 464 437 456	2 to 5 (Mainly 3 to 4) 1 to 3 2 to 5 (Mainly 3 to 4) 1 to 4	Dark golden-brown coating of lacquer. " " "	Sand-blasted, marked temper colouring. Sand-blasted. Sand-blasted. Sand-blasted and marked temper colouring	Poor " " "
0·0045 0·004	435 451	1 to 4 (Mainly 3) 1 to 3 (Mainly 3)	Green lacquer. "	Sand-blasted and showed blue temper colours.	Fair "
— —	416 420	— —	— —	Probably sand-blasted. Shot-blasted.	Good
0·0045 0·0045 0·0045 0·0045	434 432 447 445	1 to 4 (Mainly 2 and 3) " " "	Greenish-brown lacquer. " " "	Sand-blasted and slight temper colouring. " "	Poor. Good. Poor. Good.
0·009 0·023 0·0075 0·020	414 406 410 400	1 to 4 (Mainly 3) " 1 to 4 (Mainly 3) "	No coating. " " "	Sand-blasted. " " "	Fair. " Fair. "



Magnetic Etch Test

In none of the springs were any cracks or other defects revealed by magnetic etching.

Macroscopical Examination

Of the springs examined after light etching only those of the Mercedes-Benz D.B. 601A (Report No. 18), and to a lesser extent the Bramo Fafnir 323P (Report No. 47)

Fig. 85.—Longitudinal section of Jumo 211A spring. Picric-acid etch. x 300.

TABLE X.—DIMENSIONS

Report No.	18.	B.M. 1.	119.		18.		18.			B.M. 2.	
Type of Engine.	Jumo 211A.	Jumo 211D.	Jumo 211.F.1.		B.M.W. (Type 132K.)		Mercedes-Benz D.B. 601A.			Mercedes-Benz D.B. 601A.	
			Inlet.	Exh't.	Inlet.	Exh't.					
Diameter of wire; in.=d	0·183	0·185	0·187	0·186	0·205	0·208		0·154		0·152	
Number of coils = n	7½	7	7	7	7	6¾		5¾		5¾	
Number of active coils	6	5½	5½	5½	5½	5¼		4¼		1	
Diameter of coils, in.—							Top	Mid.	Bot.	Top	Bot.
External	1·803	1·75	1·788	1·788	2·136	2·141	1·457	1·554	1·651	1·44	1·63
Internal............	1·437	1·38	1·414	1·416	1·726	1·725	1·149	1·246	1·343	1·136	1·326
Mean = D	1·620	1·565	1·601	1·602	1·931	1·933	1·303	1·406	1·497	1·288	1·478
Free height, in. = L	3·047	2·75	2·791	2·787	3·035	2·866		2·055		2·090	
Solid height............	1·281	1·203	1·215	1·209	1·332	1·300		0·808		0·798	
Total deflection	1·766	0·872	1·576	1·578	1·703	1·566		1·247		1·292	
Pitch of coils = P	0·549	—	0·547	0·549	0·572	0·552		0·527		—	
Length of wire, in.	38·18	34·42	35·2	35·2	42·47	40·99		25·29		25·0	
Head of spiral	Right	Right	Right	Right	Right	Right		Right		Right	
Weight of springs, oz. ..	4·27	—	4·00	4·00	5·77	5·70		1·96		—	
Stiffness, lb./in.	—	82	—	—	—	—		—		78	

TABLE XI.—DIMENSIONS

Report No.	18.	B.M.1.	119.		18.		18.			B.M.2.	
Type of Engine.	Jumo 211A.	Jumo 211D.	Jumo 211.F.1		B.M.W. (Type 132K.)		Mercedes-Benz D.B. 601A.			Mercedes-Benz D.B. 601A.	
			Inlet.	Exh't.	Inlet.	Exh't.					
Diameter of wire, in. = d	0·130	0·134	0·135	0·135	0·175	0·178		0·119		0·115	
Number of coils = n	10	7½	7¾	7¾	8¼	8½		7¼		7¼	
Number of active coils	8½	6	6¼	6¼	6¾	7		5¾		5¾	
Diameter of coils, in.—							Top.	Mid.	Bot.	Top.	Bot.
External	1·282	1·420	1·325	1·322	1·590	1·595	1·117	1·167	1·217	1·090	1·190
Internal............	1·022	1·152	1·055	1·062	1·240	1·239	0·881	0·929	0·979	0·860	0·960
Mean = D	1·152	1·286	1·188	1·195	1·415	1·417	0·998	1·048	1·098	0·975	1·075
Free height, in. = L ..	3·000	2·420	2·558	2·488	2·820	2·754		2·076		2·085	
Solid height............	1·235	0·938	0·979	0·979	1·356	1·424		0·803		0·776	
Total deflection.........	1·765	1·482	1·579	1·509	1·464	1·330		1·273		1·309	
Pitch of coils = P	0·385	—	0·448	0·453	0·398	0·392		0·376		—	
Length of wire, in.	36·20	30·3	28·9	29·1	36·69	37·83		23·87		23·3	
Head of spiral..........	Left	Left	Left	Left	Left	Left		Right		Right	
Weight of springs, oz. ..	2·08	—	1·72	1·72	3·75	4·02		1·12		—	
Stiffness, lb./in.	—	59	—	—	—	—		—		58	

and the Jumo 211F 1 showed evidence of draw marks. Otherwise all the springs were free from defects.

Hardness Tests

The hardness of the springs in general varied from 391 to 464 V.P.N., which is equivalent to a range of tensile strength of 81 to 96·5 tons per sq. in. The Jumo

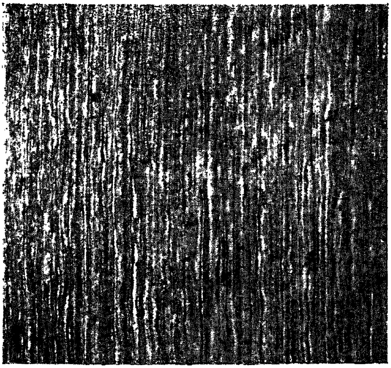


Fig. 86.—Longitudinal section of Jumo 211A spring. 2% nitric-acid etch. x 50.

OF OUTER SPRINGS.

B.M. 3.		90.						18.	B.M.4.	47.		77.	
Mercedes-Benz D.B. 601N.		Mercedes-Benz D.B. 601N.						Bramo Fafnir 323P.	Bramo Fafnir 323P.	Bramo Fafnir 323P.		Italian Fiat A. 80R.C.41.	
		Inlet.			Exhaust.					Inlet.	Exh't.	Inlet.	Exh't.
0·153			0·154			0·154		0·217	0·216	0·218	0·216	0·207	0·207
5¾			5¾+			5¾		6½	6½	6½	6½	6	6
4			4¼+			4¼		5	5	5	5	4½	4½
Top	Bot.	Top	Mid.	Bot.	Top	Mid.	Bot.						
1·44	1·63	1·464	1·557	1·650	1·474	1·562	1·650	2·115	2·095	2·120	2·107	2·175	2·175
1·134	1·324	1·156	1·249	1·342	1·166	1·254	1.342	1·681	1·663	1·681	1.675	1·761	1·761
1·287	1·477	1·310	1·403	1·496	1·320	1·408	1·496	1·898	1·879	1·902	1·891	1·968	1·968
2·000			2·012			2·038		2·937	2·940	2·940	2·901	2·420	2·435
0·803			0·808			0·808		1·302	1·296	1·308	1·296	1·138	1·138
1·197			1·204			1·230		1·635	1·644	1·632	1·605	1·282	1·297
—			0·462			0·514		0·579	—	0·594	0·599	0·563	0·543
24·97			25·34			25·44		38·76	38·37	38·84	38·62	37·11	37·11
Right			Right			Right		Left	Left	Left	Left	Right	Right
—			2·07			1·96		6·09	—	6·09	6·09	5·24	5·24
80			—			—		—	108	—	—	—	—

OF INNER SPRINGS.

B.M. 3.		90.						18.	B.M.4.	47.		77.	
Mercedes Benz D.B. 601N.		Mercedes Benz D.B. 601N.						Bramo Fafnir 323P.	Bramo Fafnir 323P.	Bramo Fafnir 323P.		Italian Fiat A. 80R.C.41.	
		Inlet.			Exhaust.					Inlet.	Exh't.	Inlet.	Exh't.
0·1175			0·119			0·119		0·165	0·1665	0·166	0·166	0·166	0·166
7¼			7¼			7¼		8½	8½	8½	8½	7	7
6			5¾			5¾		7	6¾	7	7	5½	5½
Top.	Bot.	Top.	Mid.	Bot.	Top.	Mid.	Bot.						
1·09	1·19	1·114	1·164	1·215	1·117	1·168	1·220	1·529	1·470	1·533	1·533	1·610	1·610
0·855	0·953	0·876	0·926	0·977	0·879	0·930	0·982	1·199	1·137	1·201	1·201	1·278	1·278
0·9725	1·0725	0·995	1·045	1·096	0·998	1·049	1·101	1·364	1·3035	1·367	1·367	1·444	1·444
2·030			2·044			2·025		2·933	2·940	2·888	2·904	2·220	2·220
0·793			0·803			0·803		1·320	1·332	1·328	1·328	1·079	1·079
1·237			1·241			1·222		1·613	1·608	1·560	1·576	1·141	1·141
—			0·371			0·369		0·398	—	0·407	0·410	0·421	0·422
23·3			23·80			23·90		36·42	34·80	36·51	36·51	31·75	31·75
Right			Right			Right		Right	Right	Right	Right	Left	Left
—			1·17			1·17		3·39	—	3·39	3·39	2·87	2·87
56			—			—		—	59	—	—	—	—

211A spring (Report No. 18) and the Fiat A. 80R.C.41 springs (Report No. 77) gave the lowest hardness of the series, and the Mercedes-Benz D.B. 601A springs (Report No. 18) and the D.B. 601N inner springs (Report No. 90) the highest. A departure from this was shown by the more recent engine, Jumo 211.F.1, which gave hardness values in the region of 490–510 V.P.N., corresponding to a range of tensile strength of approximately 98/105 tons per sq. in.

Microscopical Examination

With the exception of the steels used in the production of the outer and inner springs of the Mercedes-Benz D.B. 601N engine (Report No. 90) and of the outer springs of the Bramo Fafnir 323P engine (Report No. 47), the steels from which the springs were made showed a satisfactory degree of cleanness.

In general, the inclusions consisted of angular and globular silicates and oxides and fine elongated sulphides. The silicates and oxides occurred sometimes in the form of streaks up to 0·030 in. in length.

Structure

All the samples showed a normal hardened and tempered structure which was generally banded (see Figs. 85 and 86). Decarburisation was evident on the outer and inner springs from the Bramo Fafnir 323P engines (Report Nos. 18 and 47), on the outer springs from Bramo Fafnir 323P engine (Ref. B.M. 4), and on the Jumo 211.F.1 springs (Report No. 119). The remainder were found to be free from decarburisation.

Section VIII—Gears

THIS section deals with the metallurgical examination of 17 gearwheels from enemy aircraft. Of the total two only are of Italian origin, the remainder being German. The essential data are arranged for ease of comparison in Tables XII and XIII. The compositions used for the various items resolve themselves into four types of steel and the items have, therefore, been tabulated in four groups accordingly.

The dimensions of the various gears are quoted in Table XII as approximate sizes only, with a view solely to conveying a general idea of the proportion of each item.

Appearance and Finish

The degree of surface finish on the German specimens was of a very high order. A generous radius was present at the roots of the teeth and also on the edges at the ends of the teeth. In three examples (Reports Nos. 1, 5 and 19b) a shot-blasted finish was noted on areas which were unimportant as regards fitting. In two instances (Reports Nos. 88a and 88b) the web recesses and the roots of the teeth had a smooth blue-black oxidised finish. Elsewhere these gears had a bright finish, suggestive of buffing with emery. The other German gears were generally bright finished all over. One gear (Report No. 30) was also lacquered in parts. All the tooth faces showed a cross-hatched pattern typical of a ground finish. Figs. 87 to 119 show the appearance of each type.

Fig. 87.—Sun gear, Fiat A. 80R.C.41.

The standard of finish of the two Italian specimens (Reports Nos. 84a and

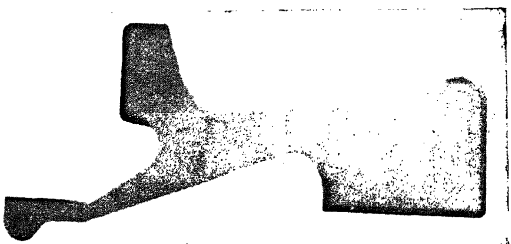


Fig. 88.—Macrostructure of sun gear, Fiat A. 80R.C.41.

84b) was appreciably inferior to the German specimens. The side faces, web and tops of the teeth exhibited fine transverse lines left from the machining operation prior to hardening, the whole having a matt appearance. The nature of the surface would not be deleterious to the performance of the gears, but would make the final inspection process more difficult to carry out and introduce risks of masking fine defects.

Marking

All the gears examined were liberally marked with figures and letters for identification purposes. With the exception of one item (5) none of the markings give any indication of a recognisable specification. No 5 was, however, marked ECN Mo130, which is probably a standard specification of the D.I.N. series, ECN being the German standards identification for a Cr-Ni case-hardening steel. Two of the wheels were marked with a date, whilst the marking generally appeared to consist of serial numbers and inspector's impressions.

Throughout the items repetition of some of the numbers occurred, but beyond indicating that the marking suggests a common origin for groups of the items no comment is offered on this aspect. The large number of markings present tend to indicate close inspection of quality of the gears throughout processing.

Composition

All the steels used were of the case-hardening types, and may be divided into four main groups :—

Italian.

(*a*) $2\frac{1}{2}$ Ni/0·6% Cr.

German.

(*b*) 2%Ni/2%Cr, together with 0·2/0·35% Mo in eight of nine steels, also 0·15/0·17 V, with Mo in four steels.

(*c*) 1·6%Ni/1·6%Cr, with Mo and Mo + V.

(*d*) 1% Cr/0·25% Mo.

Carbon.—In the German 2/2 type, and also the Italian examples, the carbon content was consistently 0·16/0·18%

Report No.	Type of Engine.	Type of Gear.
84a	Fiat engine A. 80 R.C.41	Sun gear
84b	,,	Planet gear
1	Junkers Jumo 211A	Spur gear fitted to crankshaft
5	Junkers Jumo 211A	Reduction gear
19a	Mercedes-Benz D.B. 601A	Reduction gear Pinion on forward end of crankshaft
19c	,,	Spring drive spur wheel
37	Bramo-Fafnir 323P	Planet gear
38	,,	Stationary or fixed gear
40	,,	Driving gear wheel
88a	Mercedes-Benz D.B. 601N	Airscrew reduction gear wheel
88b	,,	Airscrew reduction pinion
19b	Mercedes-Benz D.B. 601A	Spring drive pinion wheel
74a	Mercedes-Benz D.B. 601A	Airscrew shaft gear wheel
30	B.M.W. 132K	Super-charger driving sleeve
39	Bramo-Fafnir 323P	Crankshaft coupling gear
74b	Mercedes-Benz D.B. 601A	Valve and auxiliary drive wheel
92	Mercedes-Benz D.B. 601N	Rotor shaft and bevel pinion from hydraulic clutch

with one exception at 0·26%, for which there was no adequate explanation. It was noted, however, that with compositions (c) and (d) the carbon content was higher, as though to make up for deficiency in hardening capacity consequent on reduction of alloy content. The core hardness values of the two items of the 1·6% Ni-Cr composition were lower generally than those of the 2/2 Ni-Cr types, and apart from Ni-Cr content it was noted that the manganese was also lower in the former. The increase in carbon content in the Cr-Mo

TABLE XII.—SUMMARY OF GEAR WHEELS EXAMINED.

Description.	Approximate Size.	No. of Teeth.
Teeth cut radially (35 mm. tooth face) on the outside, and teeth also cut in one-half of the bore on the opposite side. Bore partly chambered and eight holes drilled through web. Surface finish inferior to German specimens	$13\frac{1}{4}$ in. dia. × $1\frac{5}{8}$ in. wide 2·5 in. min. bore	60
Bevel pinion which mates with Item 84a above. Smooth bore. Eight holes drilled through web. Series of small holes connecting root of teeth to bore in eight places	6·4 in. o/d × 1·4 in. tooth face × $2\frac{3}{16}$ in. overall × $2\frac{5}{8}$ in. bore	28
Fitted by splines to front end of crankshaft. Evidence of corrosion in the bore. Machined all over. Hollow portion between rim and hub shot-blasted	$8\frac{3}{4}$ in. o/d × $2\frac{1}{2}$ in. tooth face × 4 in. dia. bore	40
Machined all over except on hollow surfaces between rim and hub where the surface had a shot-blast finish. Gear splined in bore to fit spline shaft. Design of bore similar to Item 1 above	$12\frac{1}{8}$ in. o/d × $2\frac{1}{2}$ in. tooth face × $3\frac{1}{2}$ in. wide overall	62
Wheel surfaces smooth finished with emery. Evidence of wear on all teeth and heavy wear near the end of every fourth tooth. Splined in one half of bore. Gear chambered in the bore and generally similar in design to Item 88b	$7\frac{1}{2}$ in. o/d × $2\frac{2}{3}$ in. tooth face × $5\frac{1}{2}$ in. wide overall	36
Consists of a spur gear wth a narrow flange and without hub. The flange is bored and slotted in six places to accommodate springs and their fittings	See illustrations Figs. 12 & 13 (No. 2)	54
Bevel gear with parallel bore fitted with a ball-thrust bearing on one side. Finished smooth all over	$5\frac{3}{4}$ in. dia. × 1·4 in. tooth face × $2\frac{1}{2}$ in. overall	25
Bevel gear internally splined over half the length of the bore	$7\frac{3}{4}$ in. o/d × 1·4 in. tooth face × $1\frac{3}{4}$ in. wide overall	33
Teeth cut radially with 1·4 in. tooth face near the outer edge on one side. Bore splined for about half the width on opposite side	11·9 in. o/d × $1\frac{1}{4}$ in. overall × $5\frac{1}{2}$ in. min. bore	54
Large spur gear chambered in bore and splined both ends of bore. Roots of teeth and hollow areas between rim and hub had very smooth blue-black oxidised finish. Two teeth were broken on the gear when received. (Similar in design to Item 74a)	11·3 in. o/d × $2\frac{2}{3}$ in. tooth face × $3\frac{1}{2}$ in. overall width × 4 in. dia. bore	56
Small spur gear. Chambered in bore and splined at one end. Very similar in design to Item 19a. Roots of teeth had black oxidised surface and two teeth showed mechanical damage	$7\frac{1}{2}$ in. o/d × $2\frac{5}{8}$ in. tooth face × $5\frac{1}{2}$ in. overall width × $3\frac{7}{8}$ in. dia. bore	36
This gear incorporates the starter end. The starter end and small gear wheel had been left as-[illegible], but those portions within the spring drive 19c had been [illegible]. [illegible] chambered slightly under the teeth	See illustrations Figs. 12 & 13 (No. 1)	—
Splined in both ends of bore, web drilled with 12–30 mm. holes. Similar in design to Item 88a	$11\frac{1}{2}$ in. o/d × $2\frac{3}{4}$ in. tooth face × $3\frac{3}{8}$ in. overall width × 4 in. dia. bore	56
Flanks of the pinion coated with brass-coloured transparent lacquer and also the whole of the bore. Bore of pinion wheel also coated with a plastic deposit. This Item is bored throughout and pinion portion chambered. Connecting sleeve splined	Pinion portion $3\frac{1}{4}$ in. o/d × 1 in. tooth face × $2\frac{1}{4}$ in. bore	31
Spur wheel splined in bore and fitted in bore with a binding ring. Two holes drilled and tapped in web. Splined in sleeve portion of bore	6·9 in. o/d × $\frac{5}{8}$ in. tooth face × $2\frac{1}{2}$ in. o/a width × 3 in. bore	37
This gear has two rows of spur teeth with a row of bevel teeth in between. The bore has a serrated surface and is completely lined with white metal 1 mm. thick, which is anchored in a series of eleven holes through to the bore	$6\frac{3}{4}$ in. o/d × $3\frac{3}{8}$ in. bore × $2\frac{1}{2}$ in. o/a width; teeth faces $\frac{3}{8}$ in., $\frac{3}{4}$ in., $\frac{3}{4}$ in.	60 spur 56 beve 38 spur.
Consists of bevel pinion integral with shaft and bored for full length	Approximately 3 in. overall dia.	Approx 15

series was partly reflected in the core hardness values for this group.

Silicon.—With the exception of No. 88 the silicon content for the gears fell within the range 0·25–0·35. This, combined with the comparative absence of alumina inclusions on micro examination points to a preference for silicon over aluminium as a deoxidant. In the exceptions (Reports 88a and 88b) the silicon was lower (0·18–0·20%) and clusters of alumina were observed on the micro-section, pointing to a different and less satisfactory method of steel-making.

Manganese.—This does not call for comment other than the comparatively low figures in the 1·6% Cr-Ni group. Report 39 in the Cr-Mo group was notably higher at 1·02% than the other three items, but this did not appear

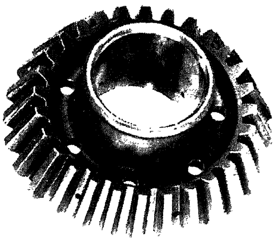


Fig. 89.—Planet gear, Fiat A. 80R.C.41.

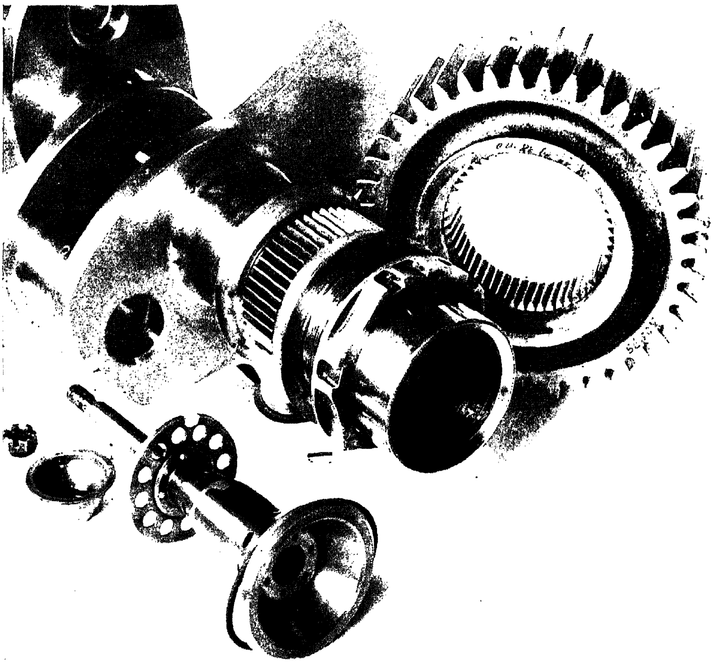


Fig. 91.—Jumo 211A spur gear assembly.

to have affected the properties of the gear.

Sulphur and Phosphorus.—The purity of the steels examined was generally of good standard and typical of basic arc electric steel. The exceptions were Reports Nos. 88a and 88b, where the sulphur was higher (0·022–0·021%), and

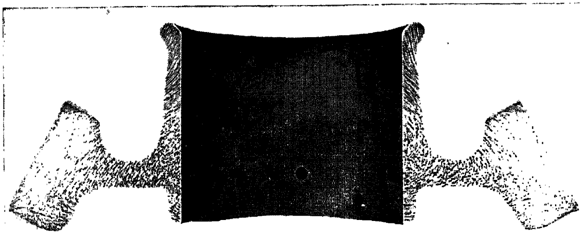


Fig. 90.—Macrostructure of Fiat A. 80R.C. 41 planet gear.

No.92 (0·019% S and 0·032% P). There was a tendency for the Cr-Mo group to be less pure than the others. In the three exceptions quoted the effect of the higher sulphur content was duly recorded in the micro-examination where sulphide inclusions were observed.

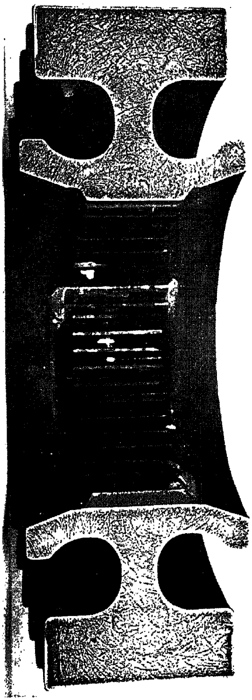


Fig. 92.—Macrostructure of Jumo 211A spur gear.

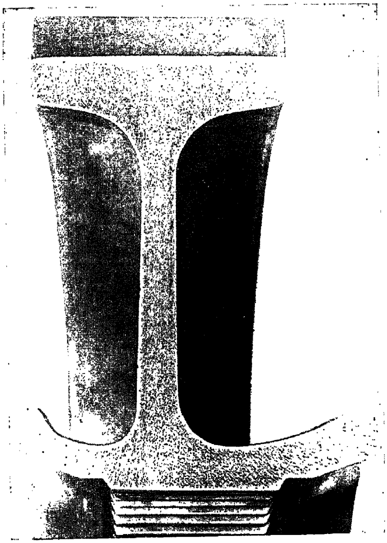


Fig. 93.—Macrostructure of Jumo 211A reduction gear.

Nickel and Copper.—There was no logical reason for the deliberate inclusion of copper in the various compositions, nor for nickel in the Cr-Mo types in the varying amounts noted. Neither element is deleterious to the steel in the quantities observed, but their presence tends to indicate that their inclusion is accidental, and that Germany has her problems with contamination of raw materials.

Vanadium.—There was no evidence to indicate why vanadium should be present in measurable amounts in six steels out of fifteen. It might on the one hand indicate an individual preference for vanadium inclusion by different steel-makers, or on the other the use of vanadium-bearing raw materials.

Chromium and Nickel.—The amounts present show no abnormal features and

TABLE XIII.—COMPOSITION, GRAIN SIZE, MECHANICAL

Report No.	Type of Engine.	Type of Gear.	Chemical Analysis, %.									
			C.	Si.	Mn.	S.	P.	Ni.	Cr.	Mo.	V.	Cu
84a	Fiat engine, A. 80 R.C.41	Sun gear	0·16	0·26	0·42	0·010	0·007	2·65	0·59	0·06	—	—
84b	,,	Planet gear	0·17	0·28	0·51	0·014	0·015	2·80	0·63	0·02	—	—
1	Junkers Jumo 211A	Spur gear fitted to crankshaft	0·18	0·33	0·42	0·018	0·014	2·18	2·18	0·24	—	—
5	Junkers Jumo 211A.	Reduction gear	0·16	0·34	0·48	0·014	0·013	2·08	1·99	0·32	0·17	0·12
19a	Mercedes-Benz DB. 601A	Reduction gear. Pinion on forward end of crankshaft	0·185	0·25	0·48	0·010	0·013	1·85	2·05	0·24	0·15	0·11
19c	,,	Spring drive spur-wheel	—	0·29	0·45	0·010	0·010	2·21	2·08	0·08	0·01	0·12
37	Bramo-Fafnir 323P	Planet gear	0·18	0·32	0·41	0·013	0·012	1·83	2·13	0·35	—	0·05
38	,,	Stationary or fixed gear	0·16	0·33	0·49	0·010	0·010	1·97	2·12	0·35	0·16	0·07
40	,,	Driving gear wheel	0·17	0·28	0·55	0·013	0·006	1·93	2·10	0·30	0·16	0·08
88a	Mercedes-Benz D.B. 601N	Airscrew reduction gear wheel	0·26	0·18	0·50	0·022	0·015	1·98	1·83	0·27	—	—
88b	,,	Airscrew reduction pinion	0·16	0·20	0·12	0·021	0·015	1·98	1·90	0·29	—	—
19b	Mercedes-Benz D.B. 601A	Spring drive pinion wheel	0·20	0·29	0·30	0·010	0·011	1·60	1·59	0·34	0·16	0·17
74a	Mercedes-Benz D.B. 601A	Airscrew shaft gear wheel	0·23	0·30	0·24	0·012	0·008	1·56	1·58	0·32	0·13	-
30	B.M.W. 132K	Super-charger driving sleeve	0·18	0·26	0·87	0·017	0·020	nil	1·01	0·27	—	—
39	Bramo-Fafnir 323P	Crankshaft coupling gear	0·20	0·28	1·02	0·012	0·010	0·30	1·12	0·24	-	0·10
74b	Mercedes-Benz D.B. 601A	Valve and auxiliary drive wheel	0·20	0·26	0·81	0·014	0·013	0·56	1·16	0·26	—	—
92	Mercedes-Benz D.B. 601N	Rotor shaft and bevel pinion from hydraulic clutch	0·23	0·35	0·88	0·019	0·032	0·30	1·22	0·27	—	-

do not call for special comment. The use of 1·6% Cr, 1·6% Ni in items 19b and 74a seems to be deliberate as distinct from the 2/2 type, and as such is an unusual composition.

Considering the compositions generally, one cannot take any exception to them on the score of irregularity of individual elements. It is to be noted that only one of the German specimens (19c) does not contain molybdenum in an amount high enough to be considered a deliberate addition.

Macrostructure, Forging, Etc.

In every instance, macro examination has shown that the gears have been machined from forgings which have been produced in such a manner as to provide the best disposition of the grain

PROPERTIES AND CASE-HARDENING DATA OF GEAR WHEELS EXAMINED

McQuaid Ehn Grain Size.	Mechanical Properties (Hounsfield Tensometer).						Case-hardening.			
	Position.	0·2% Y.P. Tons/sq. in.	M.S. Tons/sq. in.	El., %.	R.A., %.	Equiv. Izod, Ft.-lb.	Position.	Depth.	Hardness (HD30.) Case.	Hardness (HD30.) Core.
								In.		
1—5	—	—	—	—	—	—	On teeth, splines and other places	0·05	763/774	289/372
1—6	—	—	—	—	—	—	Teeth	0·04	724/752	354/384
7	—	—	—	—	—	—	On teeth only	0·05	743	327
7	Radial Web Tang'l	51·0 51·0	66·8 66·0	21·0 20·0	63·0 60·0	68 63	On teeth only	0·04 crown 0·02 roots	692/747	348/401 (Gen. 360)
6	—	—	—	—	—	—	On teeth and about ⅜ in. externally on each hub	0·05	762/803	421/455
6	—	—	—	—	—	—	On teeth and other wearing surfaces	0·05	798/835	424
6—7	—	—	—	—	—	—	On teeth and in bore	0·06/0·08	702/732	408/436
6	—	—	—	—	—	—	All faces except internal cored face	0·06/0·08	732/752	414/424
6	Tang'l from web	60	72·9	20·0	60·0	—	Chiefly on teeth and splines, thinly elsewhere	0·04	702/732	362/380
1—5	—	—	—	—	—	—	On teeth and thinly on web	0·03/0·04	392/702	396/456
2—5	—	—	—	—	—	—	On teeth and outer surface of sleeve ends	0·04/ 0·055	732/737	410/431
6	—	—	—	—	—	—	On dogs, teeth and various other places	0·035	848/862	384/401
—	—	—	—	—	—	—	Teeth only	0·06	757/786	366/380
3	Longit from sleeve	67·0	80·0	20·0	58·0		Teeth only	0·027	680/763	380/400
6	—	—	—	—	—	—	On teeth only	0·04	672/682	419/454
—	—	—	—	—	—	—	On all teeth	0·04	618/712	431/449
2—3 with some 1	—	—	—	—	—	—	All over except threaded portions	—	766/802	—

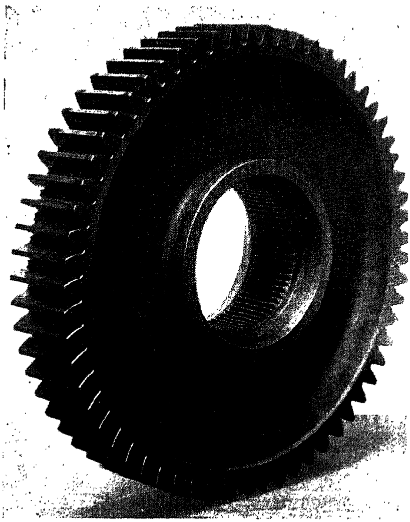


Fig. 94.—Jumo 211A reduction gear.

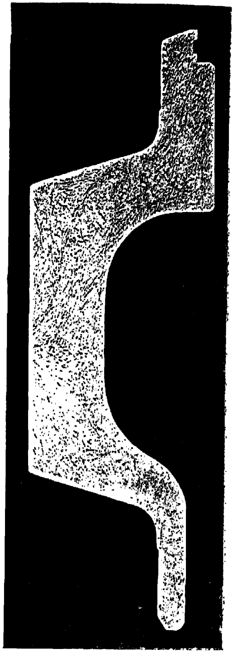
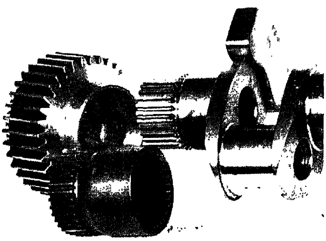
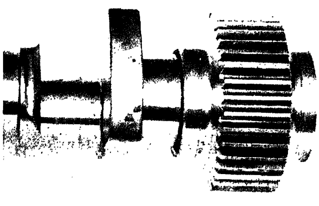


Fig. 97.—Macrostructure of Mercedes-Benz D.B. 601A reduction gear pinion on forward end of crankshaft.

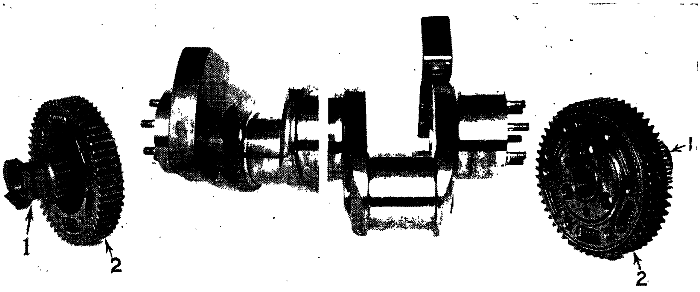
for maximum resistance to service loading. All the structures showed clear evidence of upset forging and, where possible, the profile of the gear blank appears to have been closely followed in the forging operation.

A number of the gears exhibited a rather pronounced dendritic structure, and the conclusion has been drawn that the amount of reduction of cross-section between the ingot and billet stage has been small. This observation applies particularly to Reports Nos. 1, 5, 19a, 19b, 88a and 88b. In other cases the amount of distortion in forging may have masked this effect, but it is fairly safe to conclude





Figs. 95 and 96. Mercedes-Benz D.B. 601A reduction gear pinion.



Figs. 98 and 99.—Mercedes-Benz D.B. 601A spring drive pinion (1) and spur (2) wheels.

that little importance has been attached to large reductions in cross-section at the ingot stage, but that grain direction has been carefully controlled during the final forging operation.

In the two examples in which the gear was integral with a shaft (Reports Nos. 30 and 92) the method has been followed and in the latter the bevel pinion appeared to have been upset forged on the end of a forged or rolled bar.

Certain of the gears appeared to have been made roughly to shape, followed by the removal of considerable amounts of metal in the later machining operations (Reports Nos. 84a, 37, 74b).

McQuaid-Ehn Grain Size

In the 2/2 Ni-Cr group the grain size number is 6 or 7 for all cases but two (Reports Nos. 88a and 88b), which are inclined to have a mixed but rather coarse grain size. In view of the remarks made above regarding the lower silicon content and the use of aluminium in the steel of these two items, their grain size may be considered as additional justification of the conclusion reached that in these two examples the steel-making method was below standard. In the other composition groups the grain size numbers were irregular, and no attempt

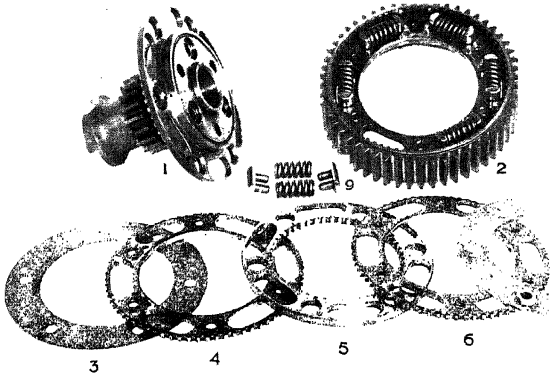


Fig. 100. Details of Mercedes-Benz D.B. 601A spring drive pinion and spur wheels.

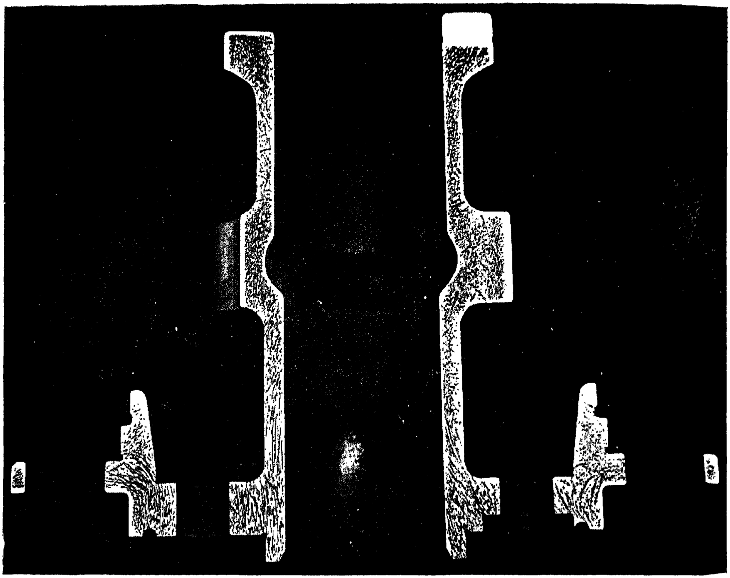


Fig. 101.—Macrostructure of Mercedes-Benz D.B. 601A spring drive pinion wheel.

appeared to have been made towards grain size control. The Italian specimens exhibited very mixed grain size.

Case Carburising and Hardening

The depth of case noted for the different specimens varied widely, the variation being between 0·027 in. and

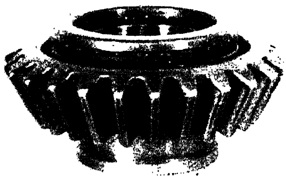


Fig. 102.—Bramo Fafnir 323P planet gear.

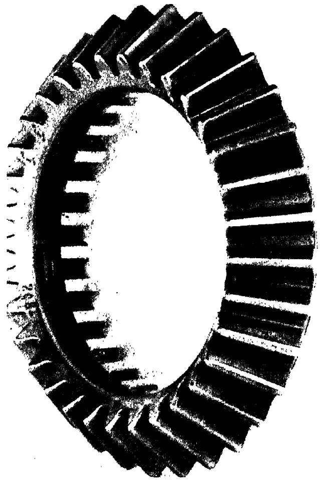


Fig. 104.—Bramo Fafnir 323P stationary or fixed gear.

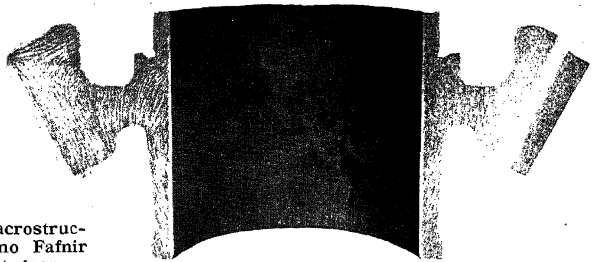


Fig. 103.—Macrostructure of Bramo Fafnir 323P planet gear.

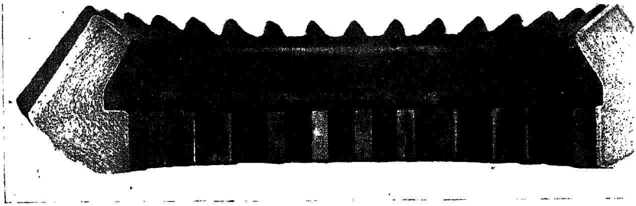
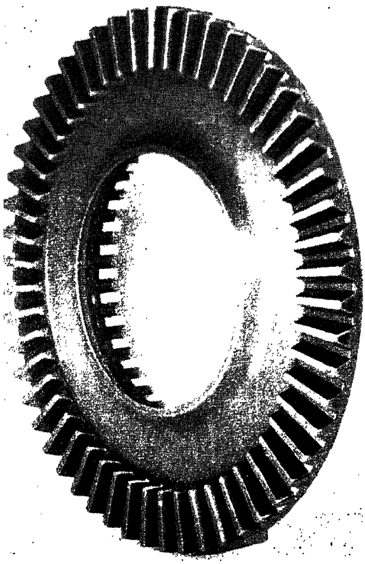
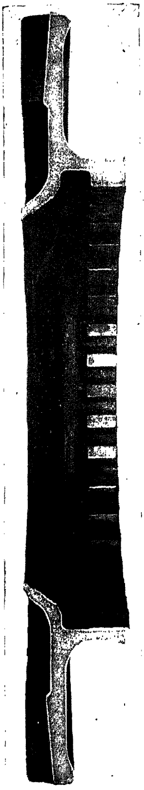


Fig. 105.—Macrostructure of Bramo Fafnir 323P stationary gear.



0·08 in. This depth was, no doubt regulated to some extent by the work to be done by the individual gears, but might also be associated with the amount of material removed from them subsequent to carburising. Regularity of the limiting line of carburising was remarked upon in Report No. 1, and machining after carburising was suggested as likely. In each individual item the carburised zone on the teeth faces was uniform in depth.

Fig. 106.—Bramo Fafnir 323P driving gear wheel.



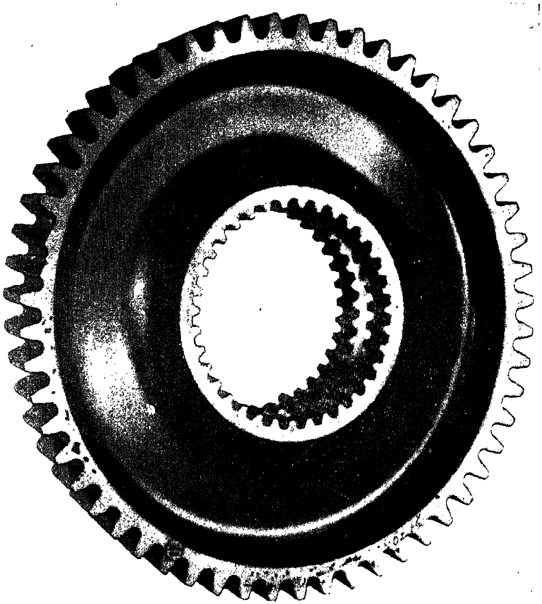


Fig. 108.—Mercedes-Benz D.B. 601N airscrew reduction gear.

Fig. 107.—Macrostructure of Bramo Fafnir 323P driving gear wheel.

In all but a small minority of the gears the micro-examination revealed the presence of carbide nodules near the outer surface of the carburised zone, and some free ferrite in the generally martensitic structure of the core. In two examples (Reports Nos. 1 and 5) attention was drawn to the possibility of the refining treatment being omitted at the hardening stage, and it seems likely on

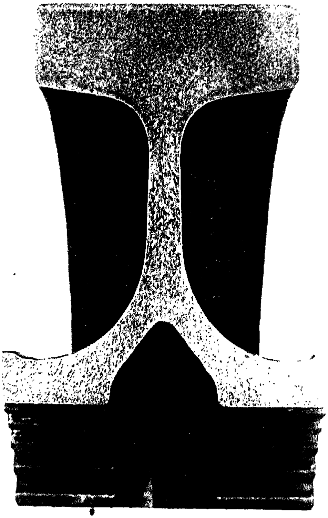


Fig. 109.—Macrostructure of Mercedes-Benz D.B. 601N airscrew reduction gear.

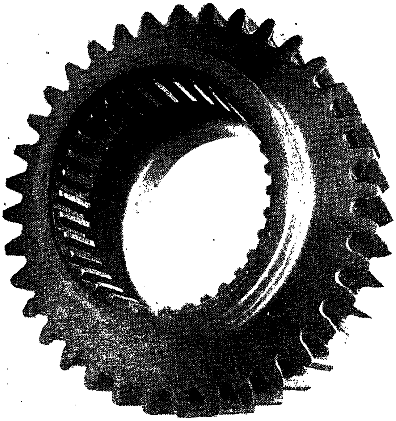


Fig. 110.—Mercedes-Benz D.B. 601N airscrew reduction pinion.

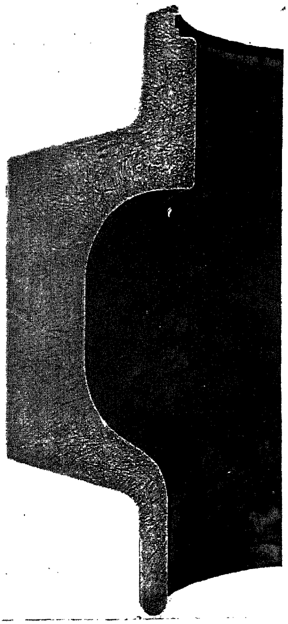


Fig. 111.—Macrostructure of Mercedes-Benz D.B. 601N airscrew reduction pinion.

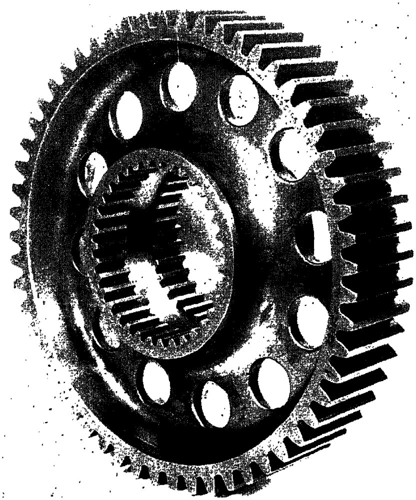


Fig. 112.—Mercedes-Benz D.B. 601A airscrew shaft gear wheel.

the information presented in the reports that after carburising a single-quenching treatment for hardening only is the more usual practice adopted.

Furthermore, it is extremely probable that the gears were lightly tempered up to 200° C. after hardening. This possibility was demonstrated with Report No. 1 by experimental heat-treatment of a specimen from the gear. Re-quenching this specimen in oil at 760° C. produced a case hardness of 824 V.P.N., as compared with the original 743. The core hardness was as before—i.e., about 327.

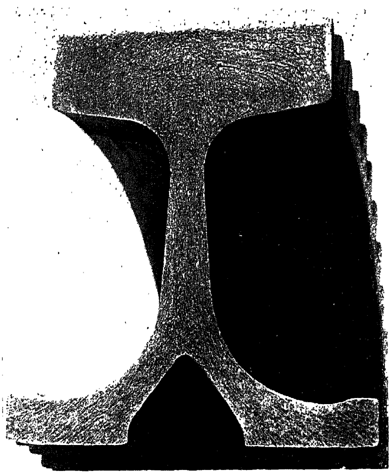


Fig. 113.—Macrostructure of Mercedes-Benz D.B. 601A airscrew shaft gear wheel.

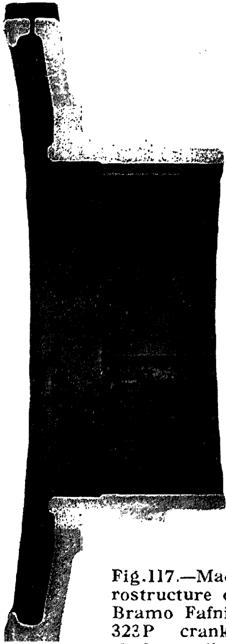
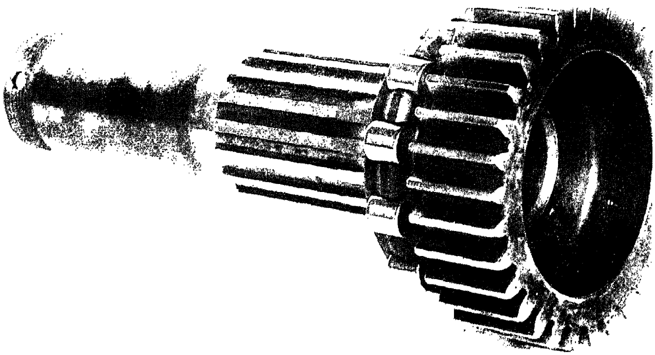


Fig. 117.—Macrostructure of Bramo Fafnir 323P crankshaft coupling gear.

On tempering the specimen at 200° C. the case hardness fell to 737.

In only two examples (Reports Nos. 74b and 92) is the absence of free carbide remarked upon, and the absence of free

Fig. 114.—B.M.W. 132K supercharger driving sleeve.



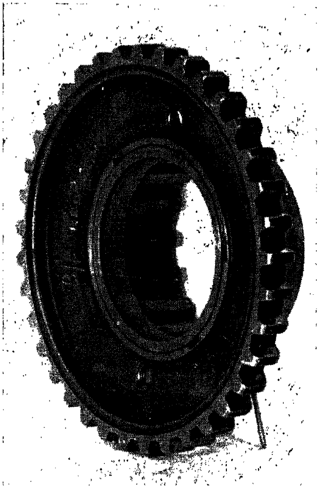


Fig. 116.—Bramo Fafnir 323P crankshaft coupling gear.

ferrite (Report No. 92) in one only; and these are in the Cr-Mo group.

Cleanness

Attention has already been drawn to the presence and significance of clusters of alumina in Reports Nos. 88a and 88b, and of sulphide particles in these, as well as in item 92. The specimens were generally free from large inclusions and stringers, the longest of the latter, where present, being reported at 0·04 ins., and this one was exceptional for the number examined (Report No. 74b).

In view of the method of forging the gears and the radial deformation produced, "stringers" have not the same significance as in rolled or forged bar, where increase in length is axial. Judged as a whole, however, the German gears examined were clean, and by British Aero-engine steel standards can be regarded as equal in this respect. Only Report 74b stands out as being notably inferior.

The two Italian gears were reported as below British and German standards, and Reports Nos. 88a and 88b again came into disfavour as being fairly clean, but below the average.

Mechanical Properties

As the gear dimensions limited test-piece sizes, the only tensile tests available on the gears were made on miniature test-pieces tested in the Hounsfield tensometer. The results obtained were indicative of good quality materials; but no further comment can be offered. The isolated shock test made on the same machine and reported as an Izod equivalent was good, but had no absolute or strictly comparative basis to warrant special consideration.

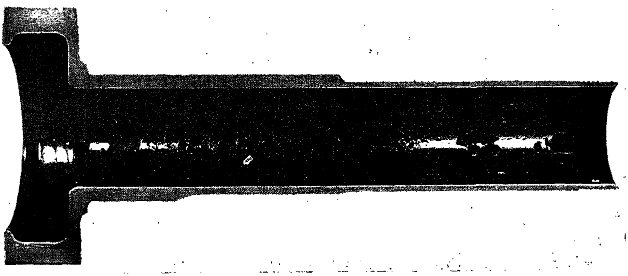


Fig. 115 Macrostructure of B.M.W. 132K supercharger driving sleeve.

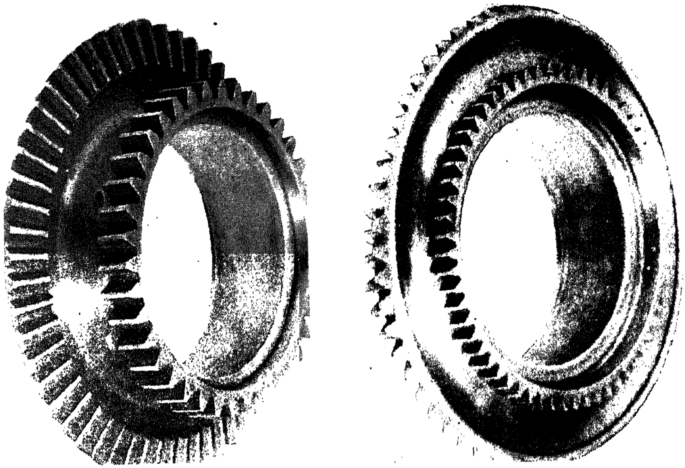
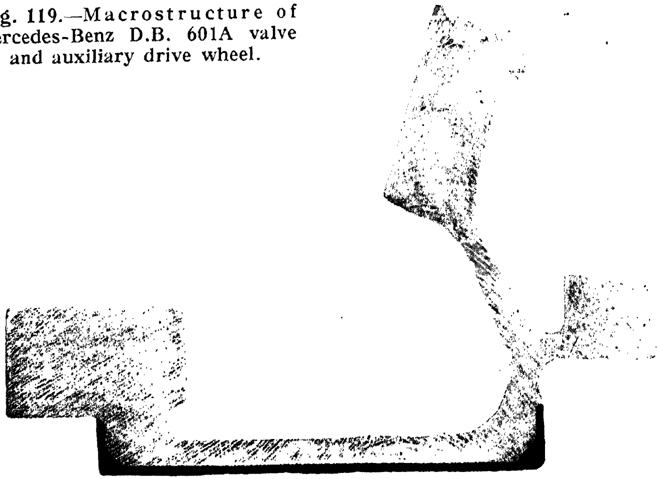


Fig. 118.—Mercedes-Benz D.B. 601A valve and auxiliary drive wheel.

Fig. 119.—Macrostructure of Mercedes-Benz D.B. 601A valve and auxiliary drive wheel.



Section IX—Bearings

DURING the course of the investigations of enemy aircraft components a number of detachable bearings and bushes were found to form part of the assembly. The results on the more important of these have been summarised and are briefly discussed below:

Crankshaft Bushes

(*a*) *BMW* 132*K* *Engine* (*Report No.* 28).—A liner with bearing inside the splined end of the shaft (Fig. 6 in Section II on Crankshafts) was found to consist of a 0·17% carbon steel liner with a cast-on lead-bronze bearing.

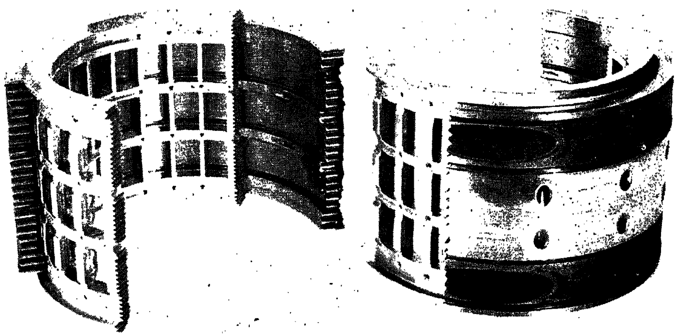
(*b*) *Bramo Fafnir* 323P *Engine* (*Report No.* 44).—Two bushes with steel liners were present in this component, one in the front end and the other in the rear half. Figs. 8 and 9 (Section II) show their respective positions in relation to the whole component. The front end bush consisted of a low carbon steel liner with a "cast-on" lead-bronze bearing, while the rear end was a 0·48% carbon steel liner with a lead rich-antimony-tin white-metal bearing.

(*c*) *Fiat A*80 *RC*41 *Engine* (*Report No.* 82).—A lead bronze bearing was cast on the inside surface of a 0·17 carbon steel liner.

Connecting Rod Bearings and Bushes

(*a*) *Mercedes—Benz DB*601*A and DB*601*N Engines* (*Reports Nos.* 21 *and* 87).—Both series of engines contained a roller race bearing at the big end of the double rod. These were very similar in design, differing only in minor points. Fig. 120 shows a photograph of one of these in two positions. Both consisted of a steel race in two halves, and were located in position at the big end by four grooves into which fitted the bolts of the double big-end rod. The roller-race cage was also in two halves, but was made of a duralumin type of light alloy. The longitudinal edges of the races and cages were machined with V-shaped notches, so that the two opposite edges fitted closely into each other and prevented

Fig. 120.—Mercedes-Benz D.B. 601N.



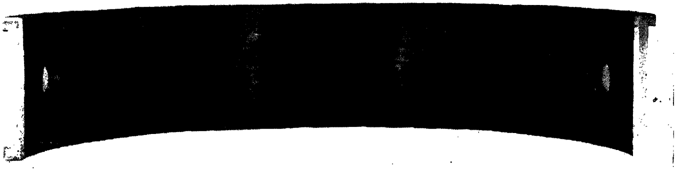


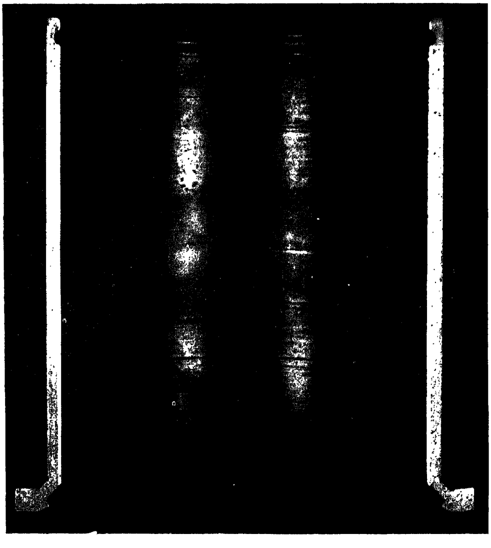
Fig. 121.—Mercedes-Benz D.B. 601A.

external movement. Several rollers were included in the examination.

The steel parts were all of a similar type of composition—viz., 1% carbon and 1–1·5% chromium. The steel had apparently been hardened and lightly tempered, and was of good quality.

The big end of the single rod of the DB601A engine contained a bush made in two halves, each half being screwed into position by two countersunk screws.

Fig. 122.—Structure at junction of steel and bronze in Mercedes-Benz D.B. 601A. x 200.



The bush was a composite structure, with a 0·12% carbon steel liner of no special quality and a cast-on lead-bronze lining. Fig. 25b (Section III) illustrates the bush in position, while Fig. 121 (this section) is a photograph of the bush away from the connecting rod, while Fig. 122 shows the etched structure at the junction of the steel and bronze.

(*b*) *B.M.W. Engine 132K* (*Report No.* 14).

This was a composite inner big-end bush used

Fig. 123.—Macrostructure of liner of B.M.W. 132K.

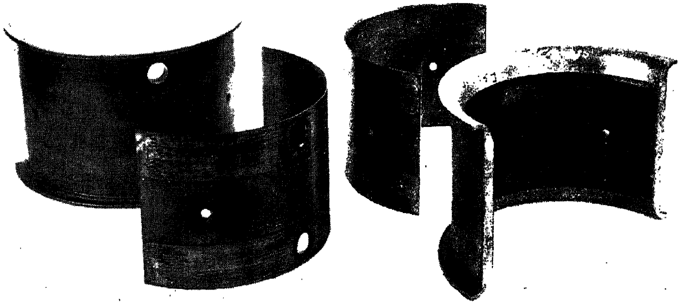


Fig. 124.—Big-end bearing of Jumo 211F1.

in the master rod. It consisted of a thin-walled cylinder with oil grooves at the inside top and bottom ends. The construction was similar to some of the other bushes mentioned—viz., mild steel lined with lead bronze. Fig. 123 shows a photograph of a section of the liner.

Junkers Jumo 211 *FI Engine* (*Report No.* 115).—The big-end bearing shown in Fig. 124 consisted of two concentric split cylinders, one of a lead-tin bronze and the other of steel with a lining of lead bronze. The steel shell was a 0·15% carbon steel.

Main Bearing from Mercedes-Benz Engine DB 601N. (Report No. 87.)

This was essentially a duralumin alloy forging surrounding a bronze-lined steel

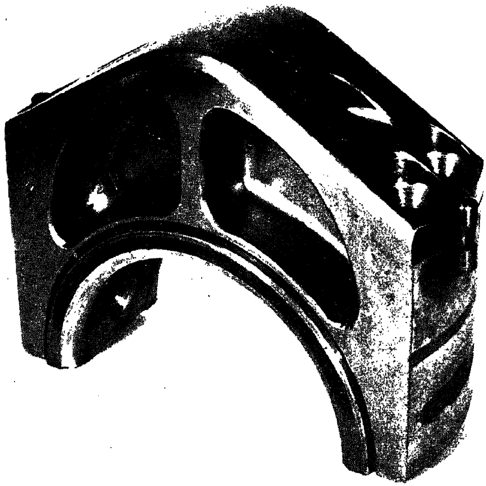


Fig. 125.–Main bearing of Mercedes-Benz D.B. 601N.

bush with a protruding steel pin on each edge of the light alloy casting (see Fig. 125). The bush was a cheap quality mild steel, 0·12% carbon, on to which a lead-bronze bearing had been cast. The pins were a steel containing 0·46% carbon.

Fig. 126.—Section of liner in main bearing of Mercedes-Benz D.B. 601N.

Fig. 126 shows a section taken through the liner.

Miscellaneous

A number of components (engine and airframe) were found to contain ball bearings of various sizes. With only two exceptions the steels were of the carbon-chromium class, containing 1% carbon with chromium varying from 0·5 to 1·5%. The composition of the races was generally at the higher end of the chromium range, while the balls were at the lower end. The exceptions were firstly, the ball bearings examined under Report No. 105, which were found to be made from a steel containing 0·42% carbon and 13·4% chromium, and, secondly, a ball thrust bearing examined under Report No. 37, in which the ball was found to contain 1% carbon, 0·87% chromium, 0·30% molybdenum, and 0·26% vanadium.

In the small end of the various connecting rods examined the bushes were in general made from phosphor bronze or pearlitic cast iron. In one instance a copper-nickel-silicon alloy was used.

Section X—Camshafts and Airscrew Shafts

A.—CAMSHAFTS

ONLY two camshafts were examined. One of these consisted of a portion from a Junkers Jumo 211A engine (Heinkel 111H) (Report No. 7), whilst the other was a complete shaft from a Mercedes-Benz DB. 601A engine (Report No. 20). Both had been case-carburised on the bearing surfaces. Their analyses and mechanical properties are given in Tables XIV and XV respectively.

The Jumo 211A camshaft included five groups of cams, each consisting of two inlet and one exhaust, while those of the DB. 601A shaft were arranged in pairs, the individual cams of each pair being in line, indicating that they probably operated both inlet and exhaust valves. There were six such pairs in all. Figs. 127 to 129 illustrate these and other features.

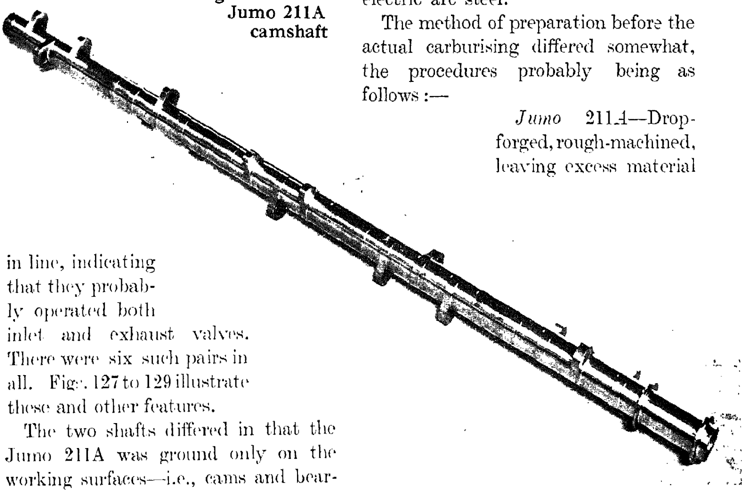


Fig. 127.—Jumo 211A camshaft

The two shafts differed in that the Jumo 211A was ground only on the working surfaces—i.e., cams and bearings—and showed a good general finish in these positions. The Mercedes-Benz DB. 601A, on the other hand, was well finished all over. In both cases there was evidence of slight scoring.

Composition

Two different types of steel were found to have been employed—viz., the Jumo 211A shaft consisted of a 1·75% chromium, 1·5% nickel, 0·22% molybdenum steel of the case-hardening type, whilst the Mercedes-Benz DB. 601A shaft was of a 1% chromium-molybdenum steel containing 1% manganese. The sulphur and phosphorus contents of both steels were very low. (See Table XIV.)

Method of Manufacture

Both shafts were probably made from electric arc steel.

The method of preparation before the actual carburising differed somewhat, the procedures probably being as follows :—

Jumo 211A—Drop-forged, rough-machined, leaving excess material where the shaft was ultimately required to be soft, and then carburised. The

part was then finished machined, the case being removed where the shaft was ultimately required in the soft condition. It was then finally heat-treated and finished ground.

Grain Size

The Jumo 211A shaft was found to have an inherent coarse grain size (Index No. 1–2), and the DB. 601A shaft was medium to fine (Index No. 4 to 6).

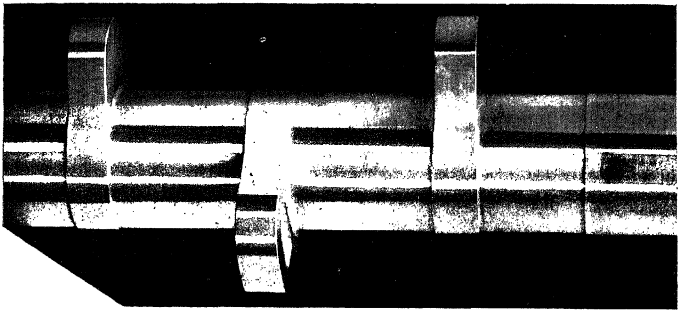


Fig. 128.—Jumo 211A camshaft (part enlarged).

TABLE XIV.
CAMSHAFTS AND AIRSCREW SHAFTS: CHEMICAL COMPOSITION.

Report No.	Type of Engine.	Component.	C.	Si.	Mn.	S.	P.	Ni.	Cr.	Mo.	Cu.	Al.	Ti.
7	Jumo 211A	Camshaft	0·13	0·22	0·38	0·008	0·010	1·59	1·75	0·22	—	—	—
20	Mercedes-Benz D.B. 601 A	Camshaft	0·23	0·38	0·94	0·010	0·012	0·32	1·07	0·22	0·06	0·06	trace
36	Bramo Fafnir 323P	Airscrew Shaft	0·34	0·23	0·40	0·009	0·016	1·83	2·06	0·11	0·09	0·11	—
83	Fiat A. 80 RC.41	Airscrew Shaft	0·29	0·24	0·70	0·008	0·010	2·98	1·08	0·51	—	—	trace

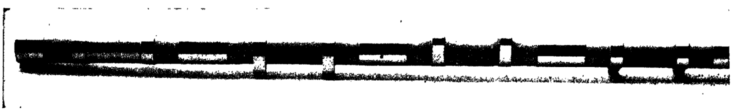


Fig. 129.—Mercedes-Benz D.B. 601A

DB. 601A.—Machined from bar stock to size, plus a grinding allowance on the wearing parts only, and then carburised. The parts not required to be hard were protected against carburising in some manner, but this appeared to have been ineffectively carried out as a patchy remnant case was observed on these parts. The shaft was then finally heat-treated.

Cleanness

Generally speaking, both steels compared reasonably well with British aircraft materials, although occasional long silicate stringers were observed in the Jumo 211A shaft.

Hardness

Both camshafts were found to be carburised, and while one composition

(Jumo 211A) was obviously a case-hardening type, the other shaft (DB. 601A) was rather an unusual type for this purpose. Being substantially nickel-free, however, the comparatively high carbon content of this latter material had no doubt been used with the idea of obtaining a satisfactorily high hardness on the uncased parts and as a substitute for nickel which is normally present with chromium in case-hardening steels of high core strength.

The hardness and tensile data may be summarised as in Table XV.

The general hardness of the wearing surfaces of the DB. 601A shaft is lower than usual for this class of part, and the erratic hardnesses found on these parts is considered to be due to insufficient quenching. Some variations in the

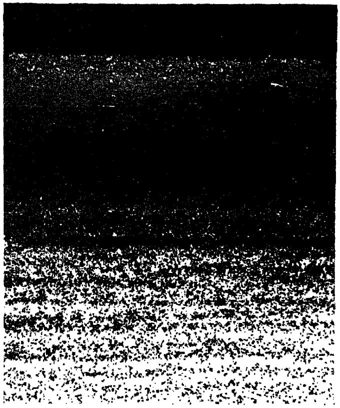
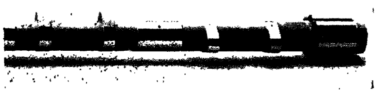


Fig. 132.—Normal case on bearing of Jumo 211A camshaft. x 40.

TABLE XV.
CAMSHAFTS AND AIRSCREW SHAFTS: HARDNESS VALUES AND MECHANICAL PROPERTIES.

Report No.	Type of Engine.	Component.	Grain Size.	Diamond Hardness. Case.	Diamond Hardness. Core.	Y.P. Tons/sq. in.	M.S. Tons/sq. in.	El., %.	R.A., %.	Izod Ft.-lb.
7	Jumo 211A	Camshaft	1 to 2	846 max.	373—390	—	—	—	—	—*
20	Mercedes-Benz D.B. 601	Camshaft	4 to 6	779 max.	450	—	—	—	—	—
36	Bramo Fafnir 323P.	Airscrew Shaft	1 to 3	—	368—383	70·1	75·8	23·0	59·6	58, 59, 64
83	Fiat A. 80 RC.41	Airscrew Shaft	5 to 6	—	340—332 BHN	72·4	77·2	19·0	60·4	47, 49, 54

* Bearing surface case-carburised.



camshaft

case hardness of the several cams from the Jumo engine were later found to be due to variation in case depth. For fuller details see Figs. 130 and 131 and Table XV.

Microscopical Examination

Both structures indicated that the

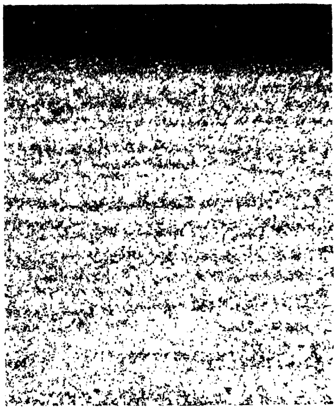


Fig. 133.—Core structure of bearing of Jumo 211A crankshaft. x 40

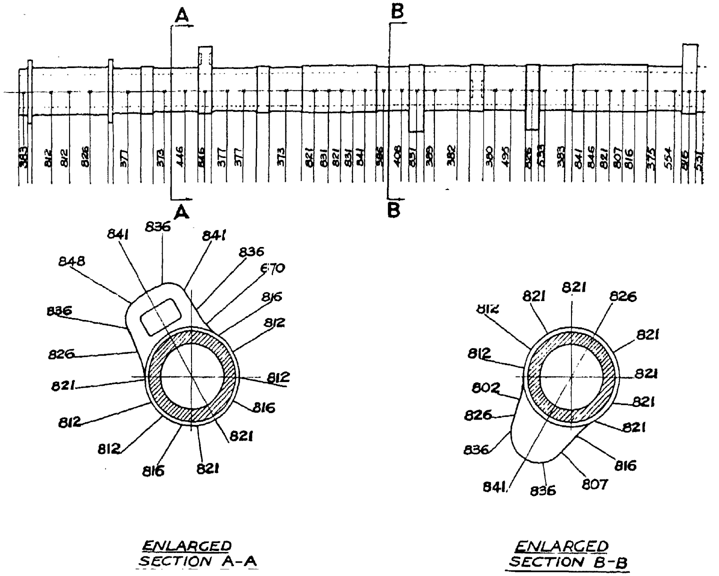


Fig. 130.—Details of Jumo

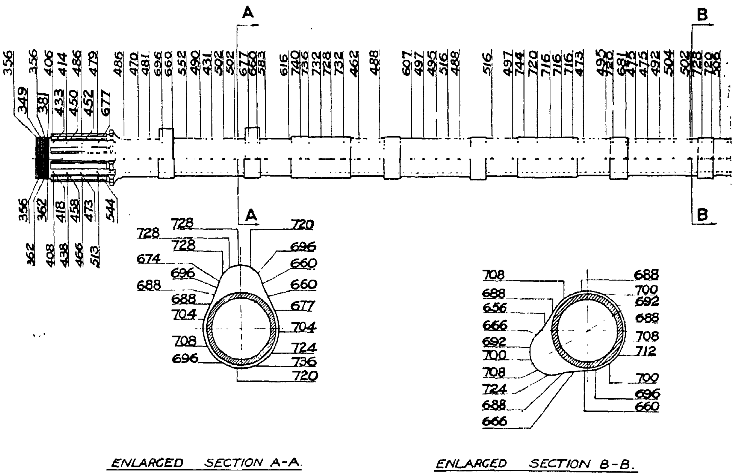
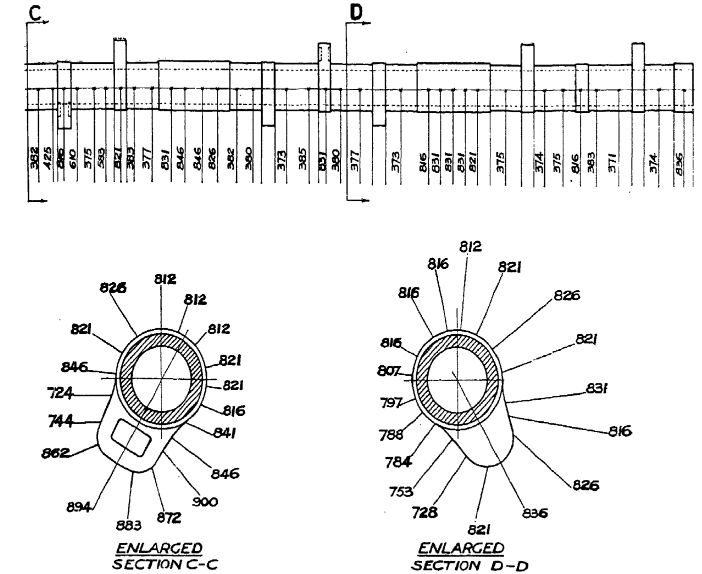
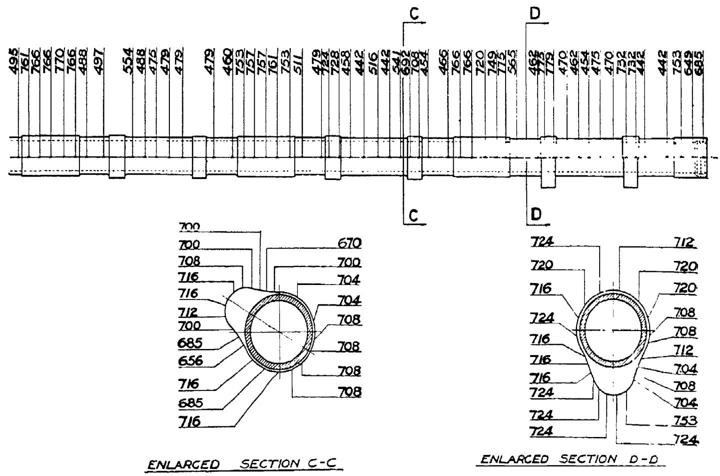


Fig. 131.—Details of Mercedes-Benz



211A camshaft.



D B. 601A camshaft.

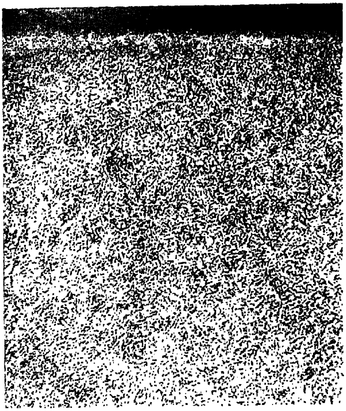


Fig. 134.—Normal case on inlet cam of Jumo 211A camshaft. x 125.

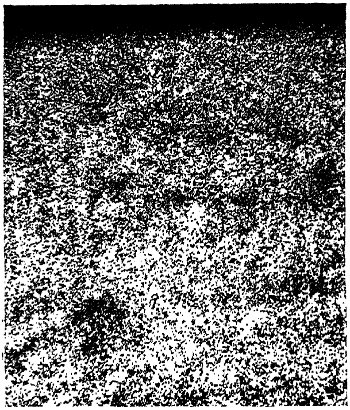


Fig. 135.—Case structure of Mercedes-Benz D.B. 601A camshaft. x 300.

shafts had been refined after carburising, and free carbide was present in the Jumo 211A shaft, but absent in the DB. 601A. Figs. 132 to 136 illustrate the case and core structures of each.

B.—AIRSCREW SHAFTS

Two only have been submitted to examination, one being from a Bramo

Fig. 136.—Core structure of Mercedes-Benz D.B. 601A camshaft. x 300.

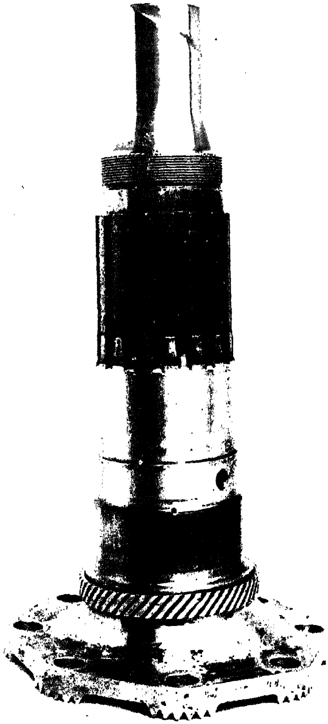


Fig. 137.—Bramo Fafnir 323P airscrew shaft.

Fafnir 323P engine (Report No. 36), and the other from the Italian Fiat A80-RC41 type (Report No. 83). A summary of the essential data is given in Tables XIV and XV.

Both appeared to be well finished, and the general appearance is illustrated in Figs. 137, 138, 141, and 142. The Italian shaft showed some irregularity in the splining towards the larger diameter end.

Composition and Method of Manufacture

Both steels were of the nickel-

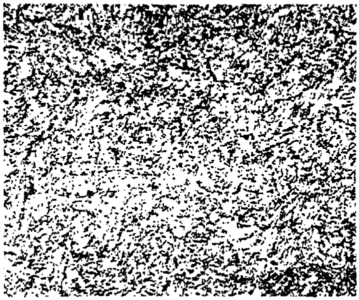


Fig. 140.—Structure of Bramo Fafnir 323P airscrew shaft. x 400.

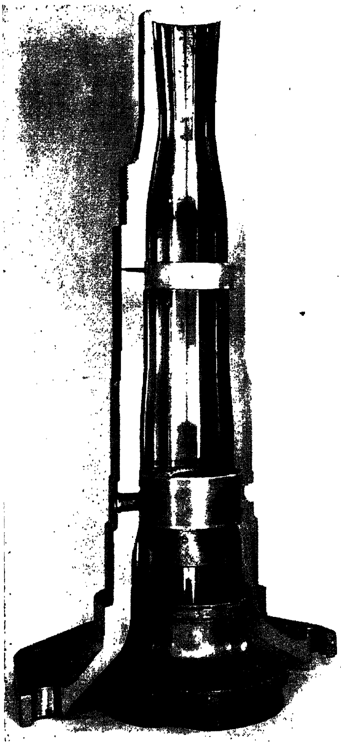


Fig. 138.—Section of Bramo Fafnir 323P airscrew shaft.

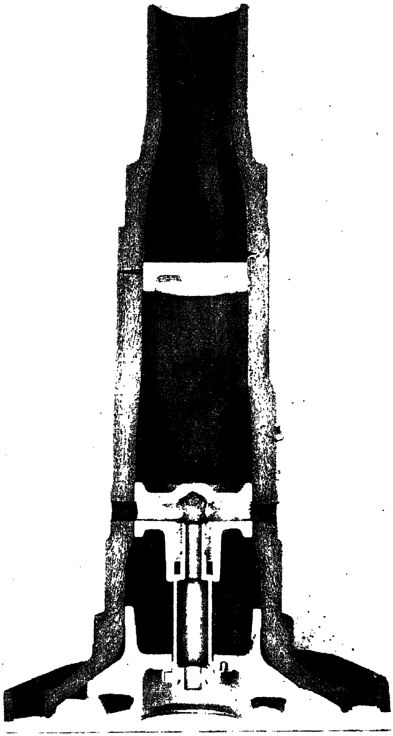


Fig. 139.—Further section of Bramo Fafnir 323P airscrew shaft.

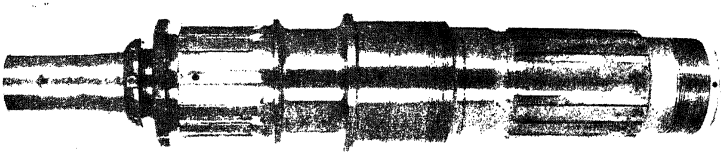


Fig. 141.—Fiat A. 80R.C.41 airscrew shaft.

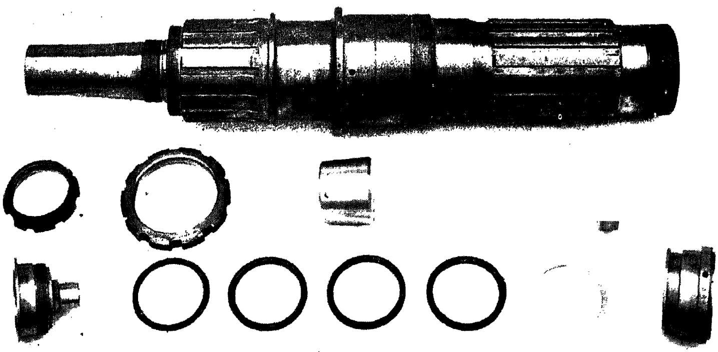


Fig. 142.—Details of Fiat A. 80R.C.41 airscrew shaft.

chromium-molybdenum class, but differed in composition as follows :—

(*a*) Bramo Fafnir 323P.—2% Ni, 2% Cr, with 0·5% Mo.

(*b*) Italian Fiat A80.RC41.—3% Ni, 1% Cr, with 0·5% Mo.

Sulphur and phosphorus contents were very low in both materials, suggesting basic arc steel manufacture. The Italian steel had evidently been titanium treated.

The methods of manufacture of the shafts were different in that the German one appeared to have been made from a tapered forged solid blank by piercing and flanging the wider end, the remainder of the centre being removed by machining. On the other hand, the Fiat shaft was considered to have been made from a solid bar, reduced by slight forging

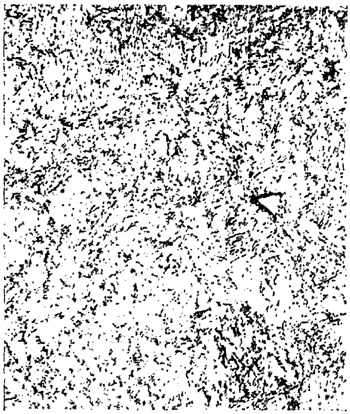


Fig. 144.—Structure of Fiat A.80R.C.41 air-screw shaft. x 500.

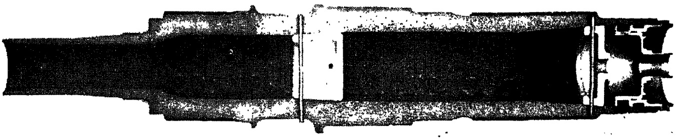


Fig. 143.—Section of Fiat A. 80R.C.41 airscrew shaft.

at the various smaller diameters. Figs. 139 and 143 illustrate these features.

Inherent Grain Size

While the Italian airscrew shaft was found to have a fairly fine inherent grain size (5 to 6), its German companion was rather coarse (1 to 3).

Hardness and Mechanical Properties

Both shafts gave uniform and fairly similar hardness values of approximately 375 V.P.N. and 336 BHN for the German and Italian types respectively. The tensile strengths were likewise similar, both being in the region of 75–77 tons per sq. in. See Table XV.

Microstructure

In each case, the etched structure was found to be fine sorbite, suggesting uniform heat-treatment by hardening and tempering. Figs. 140 and 144 illustrate these structures.

Cleanness

Both compared reasonably well with British aircraft steel.

Section XI—Castings

A NUMBER of German aircraft components were found to have been made as alloy steel castings, and in view of the high quality of these, the sections of the reports dealing with castings were abstracted and issued as a separate report by the Aero Components Sub-Committee of the Technical Advisory Committee. The salient features of the results of the examination are here summarised :—

Of the eight castings examined, five formed parts of the landing or take-off gear, the other three being parts of the fuselage. The individual components are enumerated, together with the appropriate references, in Table XVI.

Surface Appearance

All the castings had a good finish, although on many of them a considerable amount of machining had been carried out, not only on mating surfaces, but also on the more highly stressed portions. The component which had the least satisfactory surface was the take-off hook (Report 34), and, as will be observed, the quality of this particular article was, from all aspects, of a lower standard than those items associated with the landing gear. Instances of surface inclusions of sand, general roughness and surface cracks were present in the hook, whereas in the other components such defects were absent, except to the extent that some evidence of roughness and adherent sand was found in those portions which, due to the shape of the castings, were not accessible for machining and/or grinding operations.

Soundness, Etc.

An outstanding characteristic of all the castings examined was their internal soundness and freedom from contraction defects. Only two instances were noted of very slight unsoundness—viz., the shock absorber strut (Report 26) and the V connecting piece (Report 53). Whilst there is no doubt that intensive

TABLE XVII.—RESULTS OF EXAMINATION

Report	Component.	Aircraft.
26	UNDERCARRIAGE PARTS Shock absorber strut	Junkers 88
34	ASSISTED TAKE-OFF HOOK	Heinkel 111
112	PORTION OF WING ROOT FITTING	Heinkel 111—H6
49	MAIN UNDERCARRIAGE STRUT Axle and knee piece Retraction bracket	Messerschmitt 110
51	CORNER CASTING	Messerschmitt 110
53	V CONNECTION PIECE FROM CENTRE SECTION SPAR	Messerschmitt 110
65	UNDERCARRIAGE SUPPORT Head Foot Torsion Links : Upper Lower	Messerschmitt 109
66	UNDERCARRIAGE BRACKET (Port)	Messerschmitt 109

TABLE XVI.—COMPONENTS EXAMINED.

Aircraft.	Nature of Component.	Report No.	Reference.
Junkers 88	Shock absorber strut	26	Section XIII D
Heinkel 111	Assisted take-off hook	34	,, XIV
Heinkel 111 H6	Portion of wing root joint fitting	112	,, XIII C
Messerschmitt 110	Main undercarriage strut, comprising axle, knee-piece and retraction bracket	49	,, XIII D
,,	Corner bracket	51	—
,,	V connecting piece from centre-section spar	53	,, XIII B
Messerschmitt 109	Undercarriage strut, comprising head, torsion link and foot.	65	,, XIII B
,,	Undercarriage bracket	66	,, XIII B

OF CAST STEEL COMPONENTS FROM GERMAN AEROPLANES (*Continued on pages 86 & 87*)

Description of Component.	Soundness.
The connecting piece and strut are integrally cast. Machined on tubular portion and on mating surfaces of connecting piece. The inside of the strut is machined, whilst the interior of the connecting piece has not been machined, but only shot-blasted	Magnetic testing and X-ray examination revealed no unsoundness, but a section through the lugged flange and head of the central internal supporting fin shows slight unsoundness at the centre. Sulphur printing shows slight segregation only in the vicinity of the unsoundness
Roughly a triangular-shaped web flanged round the edges and stiffened by box webbing hook portion at one side of apex. In certain portions the thickness is $\frac{1}{16}$ in. in the as cast thickness. Machined on mating faces—one flange is built up by welding	Microscopic examination reveals a few blowholes
A T-shaped casting with two closely adjacent vertical portions forming the leg of the T. One end tubular	Apparently sound
Consists of an L-shaped casting with the leg of the L tubular in form. This constitutes the axle portion. The body of the knee-piece was ground except for mating surfaces, which were machined. In the case of the axle the exterior was finely ground and chromium-plated, the interior being rough-bored	Number of small holes visible on chromium plated outer surface
Broadly speaking consists of a box [illegible] casting with an integral rectangular-shaped base, having a fin projecting from upper face. The outer surface was rough, whilst the [illegible] and interior were machined	Apparently sound
This is a constituent part of a tail plane attachment, and had been machined on fitting faces The thickness of this casting is generally approximately $\frac{5}{16}$ in.	Apparently sound
V-shaped tubular construction. The arms of the V being machined to tubular shape, while the base of the V was unmachined	Microscopic examination revealed slight porosity
There are three constituent parts of this assembly which are castings. The head consists of a cap with an extension piece of roughly triangular form. This has been grit-blasted except on mating surfaces. The cored inside holes have not been cleared of sand. There is some cold lapping on the inside of the casting	Sound and free from segregation There is a small welded area This operation has been carried out prior to to heat-treatment
This is an L-shaped tube, the straight portions of the bore having been rough machined before final heat-treatment. Screwed at each end of casting	No unsoundness disclosed
Roughly triangular, with flanged edges. There are lugs at each angle, except that in the case of the upper link the lug at the apex was double	No comments
Three lugs in the form of a triangle with a boss or mass at each angle and various projecting fins. Machined on mating surfaces, remainder ground where accessible	No internal defects. Two fine surface cracks

study of the form of the components had been made in order to evolve a design in which irregular and unsuitable sections were absent, there were instances of relatively speaking large masses inter-connected by smaller sections.

The only important internal discontinuities noted were those associated with non-metallic inclusions. Where these were observed, the castings were sectioned for macro-examination in the position most likely to reveal unsoundness, if such existed. Whilst on many of the castings machining operations have been performed, thereby removing the original cast surface, there were a number of surfaces which exhibited the original condition. These latter, even in the thin sections, showed a good outline, indicating satisfactory running of the steel.

Segregation

No pronounced sulphide segregation was found, except in the few instances where this occurred locally, and in such cases it was associated with unsoundness.

Composition

The composition of the steel was similar in all the examples examined—viz., 1% chromium with 0·25% molybdenum, although one example (Report 53) gave a molybdenum value of 0·40%. Generally speaking, the steels were found to be very pure, as judged from the standpoint of the sulphur and phosphorus content. The analysis results are set out in detail in Table XVIII, and attention is drawn to the relatively high phosphorus content of the take-off hook, as compared with the other castings.

Accidentally introduced elements in the form of nickel and copper were not present to any great extent; in fact, in certain instances the nickel content was so low as to suggest either scrap specially selected from the point of view of freedom from admixture or that the charge contained a high proportion of specially pure iron.

Only in two instances had vanadium been detected, and the proportion suggested that it might have been accidentally introduced in the raw material. Where aluminium had been determined it was not present in a large proportion, which indicated that it had been added to such an extent as would obtain in normal ingot manufacturing practice. In one instance—viz., the main under-carriage strut from the Me.110

TABLE XVII contd.—RESULTS OF EXAMINATION

Report	Component.	Aircraft.
26	UNDERCARRIAGE PARTS Shock absorber strut	Junkers 88
34	ASSISTED TAKE-OFF HOOK	Heinkel 111
112	PORTION OF WING ROOT FITTING	Heinkel 111—H6
49	MAIN UNDERCARRIAGE STRUT Axle and knee piece Retraction bracket	Messerschmitt 110
51	CORNER CASTING	Messerschmitt 110
53	V CONNECTION PIECE FROM CENTRE SECTION SPAR	Messerschmitt 109
65	UNDERCARRIAGE SUPPORT Head Foot Torsion Links: Upper Lower	Messerschmitt 109
66	UNDERCARRIAGE BRACKET (Port)	Messerschmitt 109

(Report No. 49)—titanium oxide inclusions were found to be present in the microstructure, which suggested the possibility that this particuiar element had been employed as a deoxidiser. There were also traces of titanium in the shock absorber strut from the Junkers 88 (Report No. 26).

Steel-making Process

The indications were that all these steels had been made by the basic electric furnace process, although the possibility that a process involving a final melting in a high-frequency furnace could not be ruled out.

The inherent grain size, as determined by the McQuaid Ehn method, was, generally speaking, of the fine-grained type. It was reasonably consistent in the samples examined, with the exception of the take-off hook, which exhibited a mixed grain of 1 to 6 and the portion of the wing root joint fitting (Report 112) which also gave a mixed grain of 1 to 2 and 5.

OF CAST STEEL COMPONENTS

Micro Examination.	Inclusion Examination.	McQuaid Ehn Grain Size
Acicular structure of tempered martensite. Slight dendritic segregation indicated by uneven response to etching	Rounded inclusions few in number. Indicative of good quality basic steel. Probably electric-arc furnace process. There is a possibility that the acid H.F. may have been used	5
Small dendritic grain structure consisting of ferrite and sorbitic pearlite. Decarburisation on all cast surfaces to depth of 0·027 in. Complete decarburisation to depth of 0·006in. Many fine cracks in sorbite situated in inter-dendritic area. Some cracks associated with inclusions. *Weld Metal:* Finely dispersed sorbitic pearlite with small areas of ferrite. Decarburisation [illegible] of 0·006 in. *Junction:* Coarse structure. Decarburisation to depth of 0·006 in.	Fairly dirty random distribution of small globuar oxides and silicates; few small sulphides and occasional larger slag inclusons. Tendency to group formation of inclusions—slight segregation of sulphides and oxide sulphides adjacent to unsoundness. Weld metal cleaner than parent metal—small globular sulphides and silicates	1—6 5
Hardened and tempered structure. Fine-grained sorbite	Inclusion count—30; very few inclusions	1—2 and 5
Fine crystal structure consisting of dense sorbite having a mottled appearance, indicative of the cast dendritic pattern. A number of inter-dendritic cracks were found to be associated with inclusions	Slightly dirty random distribution of small angular and globular oxides and silicates and a few larger mono-phased sulphides and angular titanium inclusions	6—8 mainly 6
Similar structure to axle and knee-piece casting	Similar to axle and knee-piece casting	Not examined
Hardened and tempered condition	Inclusion count value:—27	5 and 8
Hardened and tempered structure. Sorbite with intermingled ferrite. Slight coring	Inclusion count—30	4—6
Fine-grained close sorbite with some intermingled ferrite	Small number of globular sulphides and silicates, having a random distribution. Clean for basic E.F. process	7
Fine-grained sorbite with some intermingled ferrite	Few inclusions. Steel clean	4
Both castings have a sorbitic structure. One was fine-grained, but the other was rather coarse—appeared to have been slightly overheated in treatment	Very few small inclusions. Steel clean	3—5
Tempered martensite slightly lacking in uniformity, due to differential response to heat-treatment and etching. Crack is a pocket of unsoundness 0·16 in. deep < 0·5 in. thick. Oxidised and decarburised in vicinity of crack	Inter-dendritic distribution. Indicative of good quality basic electric furnace steel	5

TABLE XVIII.—COMPOSITION AND MECHANICAL

Report No.	Component.	Aircraft.	Composition, %. C.	Si.	Mn.	S.	P.	Ni.	Cr.	Mo.	Cu	Other Elements.
26	UNDERCARRIAGE PARTS Shock absorber strut	Junkers 88	0·23	0·45	0·64	0·004	0·005	0·02	0·94	0·25	0·10	Ti 0·003 Al 0·063
34	ASSISTED TAKE-OFF HOOK	Heinkel III	·265	0·32	0·63	0·007	0·033	nil	1·01	0·25	0·14	O_2 0·004 N_2 0·009
112	PORTION OF WING ROOT FITTING	Heinkel III,H6	0·23	0·40	0·66	0·008	0·013	0·05	0·93	0·14	0·11	O_2 0·001 N_2 0·003 H_2 0·0001
49	MAIN UNDER-CARRIAGE STRUT Axle and knee piece	Messerschmitt 110	0·26	0·39	0·64	0·004	0·010	0·14	0·98	0·20	—	—
	Retraction bracket		0·29	0·35	0·71	0·005	0·013	0·09	0·89	0·18	—	—
51	CORNER CASTING	Messerschmitt 110	0·24	0·41	0·61	0·005	0·010	0·07	0·92	0·23	0·14	—
53	V CONNECTION PIECE FROM CENTRE SECTION SPAR	Messerschmitt 110	0·28	0·44	0·59	0·008	0·016	0·10	0·99	0·10	0·17	—
65	UNDERCARRIAGE SUPPORT Head	Messerschmitt 109	0·26	0·40	0·72	0·011	0·015	0·20	0·83	0·13	0·18	Al 0·08
	Foot		0·19	0·49	0·65	0·014	0·012	0·11	0·89	0·24	0·18	V 0·05 Al 0·02
	Torsion Links: Upper		0·23	0·44	0·66	0·018	0·010	0·12	0·86	0·18	—	V 0·05
	Lower		0·23	0·42	0·68	0·015	0·009	0·16	0·91	0·19	—	V 0·05
66	UNDERCARRIAGE BRACKET (Port)	Messerschmitt 109	0·25	0·42	0·69	0·009	0·012	0·08	0·98	0·12	0·10	Al 0·08

Test-piece Location.	Test-piece Dimensions.	Mechanical Tests. L.P.	Proof Stress. Tons/sq. in. 0·1 %.	0·2 %.	0·5 %.	Y.P. Tons/sq. in.	M.S. Tons/sq. in.	Elongation, %.	R.A. %.	Izod, Ft.-lbs.	Hardness.
Connecting piece	0·050 in. × 0·078 in.	—	—	—	—	67·9	69·5	7·5 (8 in. GL)	—	—	—
		Slightly defective.						3·0 (2·4 in. GL)			
Shock absorber strut	0·050 in. × 0·072 in.	36·0	57·2	61·6	66·4	—	72·2	17·3 (0·75 in. GL) 7·0 (2 in. GL)	—	—	302/321 Brinell
Body	1·1 in. G.L. × 0·3115 in. dia.	Bend ½ in. × ¼ in. section. Radius ⅛ in.—101° cracked.					59·2	18·2	50·0	35, 28, 29	271/306 VPN
Hook Weld metal											226/262 VPN 204/287 VPN
Horizontal portion of T.	0·177 in. dia.	—	—	—	—	53·7	56·9	20·0	54·0	—	255—269
Axle	Gauge length = $4\sqrt{\text{sect. area}}$	—	—	—	—	—	75·0	8·0	25·5	—	327/354 VPN on casting
Knee piece	As above	—	—	—	—	—	77·0	9·0	25·0	—	366 VPN
Retraction bracket generally	—	—	—	—	—	—	—	—	—	—	324/336 VPN
Casting	0·137 in. × 0·145 in.	—	—	—	—	61·5	66·0	23·5 $4\sqrt{A}$	55·0	—	302/311 Brinell
Parallel to one arm of V	0·157 in. dia.	—	—	—	—	45·9	52·9	24·0	67·0	—	269 Brinell
Parallel to main bearing	Tensile, 0·357 in. dia. × 1¼ in. G.L. Izod, 10 mm. sq.	—	—	—	—	—	61·0	14·0 OMH	46·0	34, 38	286 Brinell Uniform over casting
From axle portion	Tensile, 0·1 in. × 0·625 in. × 1 in. G.L. Izod : Avery test-piece, ⅜ in. × $\frac{3}{16}$ in.	—	—	—	—	—	62·6	17·5	43·4	15, 15 (Actual). Izod equivalent 70	300 VPN on casting
Flange portion of upper link	Tensile, 0·125 in. × 0·5 in. 0·1 in. G.L. Izod. ⅜ in. × $\frac{3}{16}$ in. Avery test-piece	—	—	—	—	—	67·0	16·5	35·0	12, 11, 12½ (Actual). 47/51 Izod equivalent	300 VPN on both castings. Uniform
From rib	0·60 in. × 0·20 in. × 2 in. G.L.	50·5	59·4	60·3	61·2	—	66·1	10·0 (2 in.) 12·8 $4\sqrt{A}$	—	—	—

Cleanness

The castings were all moderately clean from the standpoint of inclusions with the exception of the take-off hook where the lower quality was again evinced.

Microscopical Examination

Examination of the structure indicated that all the components were in the hardened and tempered condition, and that this heat-treatment had been carried out satisfactorily. The only criticism which could be made was with regard to one of the torsion links from the under-carriage strut of the Messerschmitt 109, in which there were indications of over-heating during the hardening operations. In a limited number of instances there were internal microscopic cracks which appeared to be associated with inclusions. (See Table XVII, pages 86 and 87.)

Mechanical Tests

Mechanical test-pieces have been cut from the castings and the test results are given in Table XVIII., together with an indication of the locations of the test-pieces.

The elongation values obtained on castings of a given tensile strength varied rather widely, and in some instances they were as high as might have been expected from wrought articles conforming to British Aircraft Specifications. The high degree of purity in some of the German components was so marked that an analysis of the mechanical test results considered in conjunction with this has been abstracted and is set out in Table XIX.

TABLE XIX.—ANALYSIS OF MECHANICAL TEST RESULTS.

Report No.	Aircraft.	Component.	Tensile Strength, Tons/sq. in.	El., %.	S., %.	P., %
49	Messerschmitt 110	Knee-piece	77·0	9	0·005	0·013
49	,,	Axle	75·0	8	0·004	0·010
26	Junkers 88	Shock absorber strut	72·7	17·3	0·004	0·005
65	Messerschmitt 109	Torsion link	67·0	16·5	0·018	0·010
66	,,	Undercarriage bracket	66·1	12·8	0·009	0·012
51	Messerschmitt 110	Corner casting	66·0	23·5	0·005	0·010
65	Messerschmitt 109	Head	61·0	14†	0·011	0·015
34	Heinkel 111	Take-off hook	59·2	18·3	0·007	0·033
112	Heinkel 111 H6	Portion of wing root fitting	56·9	20·0	0·008	0·013
53	Messerschmitt 110	V connecting piece from centre spar section	52·9	21	0·008	0·016
65	Messerschmitt 109	Foot	52·6	17·5	0·014	0·012

† Broken outside the middle half of test-piece.

There was necessarily considerable variation of the test-piece size which had been governed by the cross-sectional area available. The form of the test-piece was chosen to give results as regards elongation which were, or closely approximated to, an effective gauge length of four times the square root of the cross-sectional area.

The range of tensile strength from 52–77 tons per sq. in. is comparable with that covered by wrought alloy steel in British practice, whilst the elongation shows rather wide variations.

There are instances where, although the order of the strength is similar, the degree of ductility is outstanding. This was exemplified by the corner casting (Report No. 51) with a tensile strength of 66 tons per sq. in. and an elongation of 23·5%, and the shock absorber strut (Report No. 26) with a tensile strength 73 tons per sq. in. and an elongation of 17·3%. These two particular components had each a low sulphur and phosphorus content, and it would be

observed that there was a marked trend to employ the purer material in those components which possess the higher tensile strength.

When considering the case of the foot casting (Report 65), which had a relatively low ductility, having due regard to the tensile strength, it should be borne in mind that the carbon content of this particular component (0·19%) was the lowest of the series.

In only a limited number of cases had impact tests been carried out, and these showed the material to be tough, but the data were insufficient to enable any detailed conclusion to be drawn.

Welding

The only welded casting was the take-off hook. Analysis of the deposited metal revealed it to be of the same type of composition as the body of the casting. Actually, the chromium content was somewhat higher, and the carbon slightly lower than the parent metal. Microscopic examination showed that there was a good junction between the weld metal and the casting; the former being the cleaner metal.

General Remarks

Summarising, the investigations had indicated the attainment of a high degree of perfection in the production of these aircraft castings, which could only have been attained by prolonged development of technique, not only from the point of view of design, but of the whole manufacturing operation.

A noteworthy feature was the uniformity of the type of steel employed—that is, a 1% chromium 0·25% molybdenum steel. The carbon content varied from 0·19 to 0·29%, but the other constituents were normal with the exception of sulphur and phosphorus, which were of such a low order as to warrant the conclusion that they had been adopted as the result of considerable experience.

Illustrations

The various components are illustrated in the relevant sections (see Table XVI).

Section XII—Miscellaneous Engine Parts

THE parts considered in this section comprise :—(A) Fuel injection pump barrel and plunger ; (B) Hydraulic clutch ; (C) Supercharger parts ; (D) Spider ; and (E) Airscrew hubs.

A.—FUEL INJECTION PUMP BARREL AND PLUNGER

Two such parts have been examined : (1) from a Mercedes-Benz D.B. 601A engine (Report No. 73), and (2) from a Jumo 211F 1 (Report No. 121). A summary of the essential details are given in Table XX.

Figs. 145 and 146 illustrate the pump parts from both engines. The design is somewhat similar in each case, although certain small variations can be seen. The plunger of each type was a close, sliding fit into the barrel, and in each case the surfaces had a smooth lap finish.

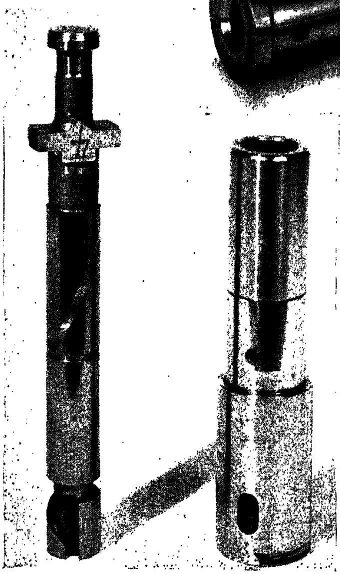


Fig. 145.—Pump plunger and barrel of Mercedes-Benz D.B. 601A.

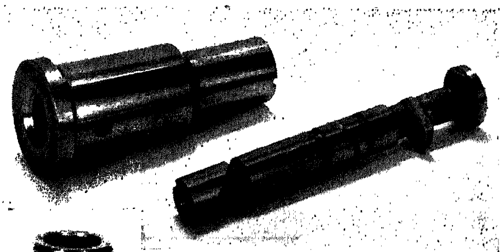


Fig. 146.—Pump barrel and plunger of Jumo 211F 1.

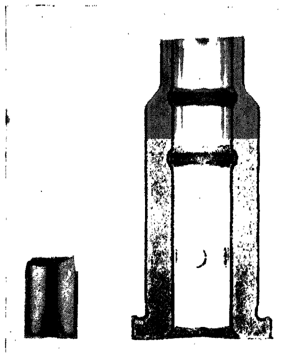


Fig. 147. Section of Jumo 211F 1 pump barrel and plunger, showing case.

Composition

Both components from the Mercedes-Benz consist of a direct hardening 1% carbon, 1½% chromium steel; while those from the Jumo 211F 1 were case-hardening types of steel. The plunger was a 1% chromium-molybdenum type, but the barrel was a plain carbon steel with 0·18% carbon. Both types were case carburised.

Method of Manufacture

All the analyses suggested that the parts had been made by the basic electric-arc process.

Cleanness

In each case the cleanness was considered to be reasonably good, and the following inclusion counts were recorded:

	Barrel.	Plunger.
Mercedes-Benz D.B. 601A	40	49
Jumo 211F 1..........	46	28

Inherent Grain Size

While the Mercedes-Benz parts were found to be of the fine-grain type (6 to 7), the Jumo parts were somewhat of a coarser rating, namely, the barrel was 4 to 6, with a few coarser grains, and the plunger was 1 to 4 (mainly, 3 to 4).

Hardness

The following hardness values were obtained :—

		Surface.	Core.
Jumo 211F1	Barrel.	882—912 D.H.	216—221 D.H.
	Plunger.	849—869 D.H.	456—459 D.H.

The core strengths of the Jumo barrel and plunger approximated to 47 and about 94 tons, respectively.

Metallographic Examination

The D.B. 601A barrel and plunger were both in the hardened and lightly tempered condition, the latter having a pronounced banded structure.

Both the barrel and the plunger of the Jumo 211F 1 pump were carbon case-hardened, the depth of case in each sample being 0·03 in. (Fig. 147). The etched structures were satisfactory (see Figs. 148 and 149).

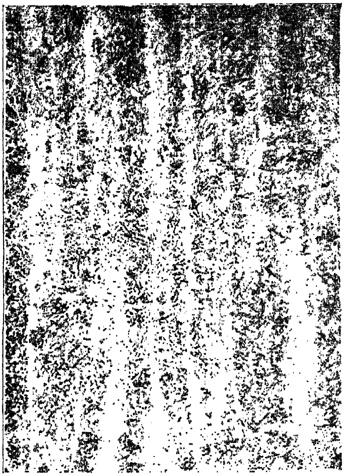


Fig. 148.—Etched structure of Mercedes-Benz D.B. 601A plunger. x 200.

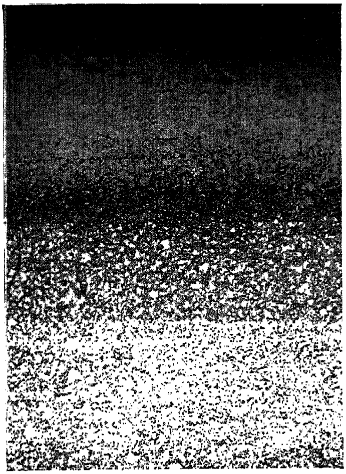


Fig. 149.—Etched structure of Jumo 211F 1 barrel. x 50.

The grain flow showed that all the parts had been machined from bar stock.

B.—HYDRAULIC CLUTCH Mercedes-Benz D.B. 601N.

Only one clutch was examined, and details are given in Table XX. Fig. 150 illustrates a general view of the clutch, while Fig. 151 shows an external view of the rotor and cover-plate separated from the casing. Fig. 152 is a view of the sectioned clutch.

The surface finish was originally smoothly machined and polished, but a large part exhibited discolorations similar to temper colours, and the examination suggested that the clutch had run hot at some stage.

The following remarks apply only to the four main parts, viz., the casing, rotor body, rotor shaft, and cover-plate.

Composition

The parts were all made from chromium-molybdenum steels, but three different compositions were involved (see Table XX), one of which contained vanadium. The molybdenum contents were rather varied.

Method of Manufacture

With the exception of the cover-plate, which contained 0·030% sulphur, the steels were probably of basic electric-arc manufacture. All parts were made as forgings. The macrostructures of the rotor body and rotor shaft, respectively, are illustrated in Figs. 153 and 154.

Inherent Grain Size

The McQuaid Ehn test showed two of the parts (casing and rotor shaft) to be of the coarse-grain type, while the other two could be classed as fine-grain steel.

TABLE XX.—COMPOSITION, GRAIN SIZE

Report	Type of Engine	Component.	C.	Si.	Mn.	S.	P.	Ni.
73	Mercedes-Benz D.B. 601A	Fuel Injection Pump.						
		Barrel	1·01	0·25	0·29	0·013	0·014	0·02
		Plunger	0·99	0·26	0·25	0·010	0·013	0·02
121	Jumo 211F.1	Fuel Injection Pump.						
		Barrel	0·18	0·30	0·36	—	—	0·67
		Plunger	0·19	0·21	0·82	—	—	0·36
92	Mercedes-Benz D.B. 601N	Hydraulic Clutch.						
		Casing	0·15	0·26	0·92	0·012	0·010	0·15
		Cover-plate	0·42	0·35	0·51	0·030	0·022	0·21
		Rotor body	0·40	0·34	0·86	0·017	0·014	0·20
		Rotor shaft	0·23	0·35	0·88	0·019	0·032	0·30
		Ball-bearing						
		Outer Race	0·96	0·29	0·29	0·014	0·017	0·07
		Race Balls	1·10	0·31	0·20	0·017	0·020	0·02
		Clamping rings	0·26	0·37	0·61	0·011	0·007	0·52
		Retaining ring	0·35	—	—	—	—	—
		Steel bearing	1·09	—	0·26	—	—	—
54	Me 110 D.B. 601A	Super-charger Intake.						
		Sheet	0·10	0·02	0·31	0·018	0·008	0·06
		Vanes	0·11	—	0·38	—	—	—
63	Fiat A. 80R.C.41	Spider	0·31	0·19	0·68	0·009	0·013	2·96
61	Mercedes-Benz D.B. 601A	Airscrew hub	0·32	0·28	0·36	0·005	0·017	1·94
62	Fiat A. 80	Airscrew hub	0·42	0·34	0·65	0·011	0·018	0·13

Cleanness

The lower sulphur steels compared reasonably well with the British Standards for aircraft steels. The cover-plate also compared quite well except for the differences in sulphur content.

Hardness

Hardness tests showed the casing to have been case-hardened along the length of the splined portion, and for a short distance along the shaft. In addition to which the rotor shaft was case-hardened on the whole of its outer surface except for the two threaded portions. Table XX should be consulted for the hardness values.

Microstructure

Both the cover-plate and the rotor body had been hardened and had fully tempered structures. The casing was carburised locally at the splined end of the shaft, and the case showed the presence of free carbide in martensite. The rotor shaft also was carburised, and both case and core showed markedly acicular martensitic structures with no free carbide present. The carbon content of this material is rather high for carburising steel.

The rotor shaft part was discussed in Section VIII.

Subsidiary Parts

A number of non-ferrous components were examined but are not included in this report. They were as follows :—

(*a*) Impeller inserts—aluminium-silicon alloy.

(*b*) Three bearings—copper alloy with iron, nickel and aluminium.

(*c*) Cage from ball bearing—copper-aluminium alloy.

Details of other steel parts are included in Table XX.

AND HARDNESS OF COMPONENTS

Cr.	Mo.	V.	Cu.	Al.	Ti.	Grain Size.	Diamond Hardness. Case.	Core.	Special Remarks.
1·33	Nil	Nil	—	—	—	6 to 7	—	813/823	
1·42	Nil	Nil	—	—	—	6 to 7	—	823	
0·07	Nil	Nil	Trace	—	—	4 to 6 (a few coarser grains)	882/912	216/221	Case carburised
1·11	0·20	Nil	0·08	—	—	1 to 4 (mainly 3 to 4)	849/869	456/459	Case carburised
1·03	0·21	—	—	—	—	Erratic 3 (mainly 2 to 4)	666/687	275/320	Partially case carburised
1·64	0·37	0·15	—	—	—	6 to 7	—	303/312	
1·70	0·17	0·18	—	—	—	6 to 7	—	364/371	
1·22	0·27	—	—	—	—	Erratic 2 (2 to 3 with some 1)	766–802	448/458	Case carburised
1·37	0·03	—	—	—	—	—	—	797–814	Inner similar
0·62	0·01	—	—	—	—	—	—	815/859	
0·90	0·21	—	—	—	—	3 to 4	—	150–156	
1·22	0·30	—	—	—	—	—	—	213	
1·43	0·02	—	—	—	—	—	—	779	
0·04	Nil	Nil	0·05	—	—	—	—	111/119	
—	—	—	—	—	—	—	—	72/98	
0·97	0·40	Nil	0·05	—	0·026	6	—	401/424	
1·88	0·38	Nil	0·05	—	—	4 to 5	—	298/315	
0·99	0·18	Nil	0·065	—	0·007	3 to 4	—	285/324	

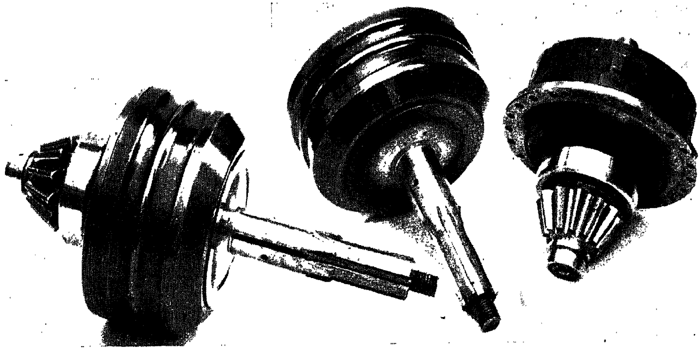


Fig. 150.—General view of Mercedes-Benz D.B. 601N clutch.

Fig. 151.—External view of rotor and cover-plate, Mercedes-Benz D.B. 601N.

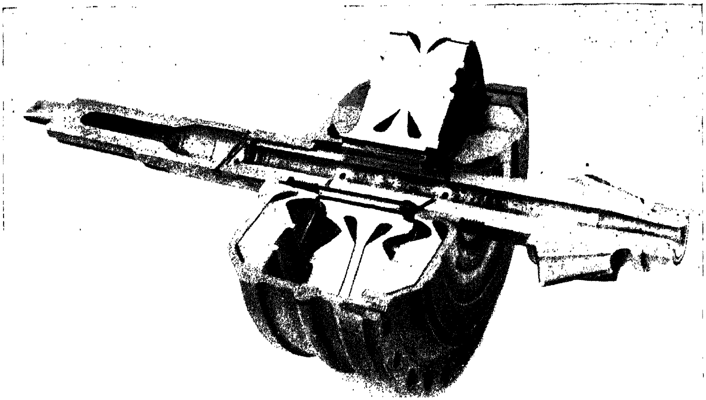


Fig. 152.—View of sectioned hydraulic clutch, Mercedes-Benz D.B. 601N.

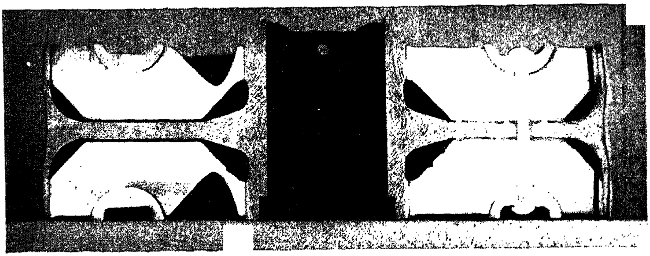


Fig. 153.—Macrostructure of rotor body, Mercedes-Benz D.B. 601N.

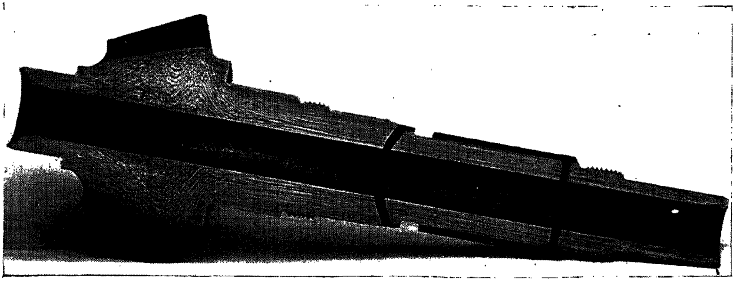


Fig. 154.—Macrostructure of rotor shaft, Mercedes-Benz D.B. 601N.

C.—SUPERCHARGER PARTS

These comprise the following :—

(1) Supercharger driving sleeve (B.M.W. 132K engine) (Report No. 30).

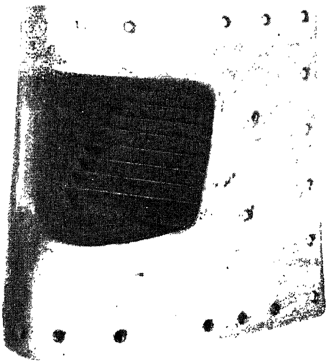
(2) Supercharger intake D.B. 601A (Mc 110) (Report No. 54).

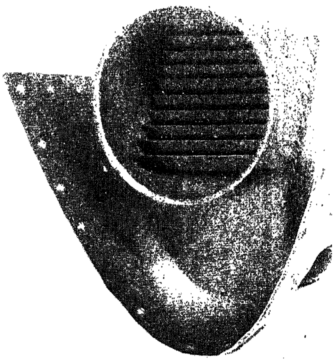
A summary of the examinations will be found in Table XX.

(1) *Supercharger Driving Sleeve.*—Details in connection with the supercharger driving sleeve (Report No. 30 above) will be found in Section VIII, where it is discussed under the heading of "Gears."

(2) *Supercharger Intake.*—Figs. 155 and 156 show two different views of the supercharger intake. The whole of the component had been built up by welding mild steel sheet with mild steel hollow vanes incorporated, all of which were in the annealed condition. The component had been lightly shot-blasted, and subsequently painted all over.

The non-metallic inclusions in the steel indicated a good-quality basic open-hearth steel, while the welds examined were good ; all being reasonably sound and free from scoriæ.





Figs. 155 and 156.—Supercharger intake for Mercedes-Benz D.B. 601A.

D.—SPIDER

Fiat A.80R.C.41 (Report No. 63)

This is a part from the variable pitch propeller mechanism, and only one example has been studied. Table XX. gives a summary of the tests carried out.

General Features

Fig. 157 illustrates the outline of the spider.

The whole of the outer surface, with the exception of the two parallel bearings on the three arms, was found to be cadmium-plated. Only small portions of the interior showed this feature.

Composition

The spider was made from a direct-hardening 3% nickel, 1% chromium, 0·4% molybdenum steel.

Method of Manufacture

The steel was of basic electric-arc manufacture, and the part had been made as a forging. Comparison with the flow structure of British forgings of this type indicated that the Italian forging was appreciably inferior (see Fig. 158).

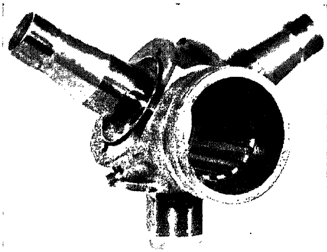


Fig. 157.—Outline of the variable-pitch propeller spider for Fiat A. 80R.C.41.

Inherent Grain Size

This test showed the material to be of the fine-grain type (No. 6).

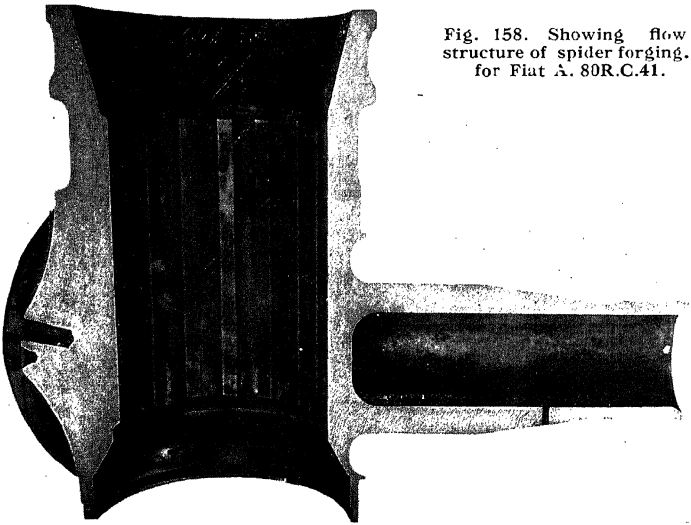


Fig. 158. Showing flow structure of spider forging. for Fiat A. 80R.C.41.

Fig. 159.—Outline of airscrew hub of Mercedes-Benz D.B. 601A.

Hardness

This was fairly uniform at 401 to 424 D.H.

Cleanness

The steel was similar in this respect to the average quality of British aircraft steels.

Micro-examination

A sorbitic structure typical of hardening and tempering was observed.

E.—AIRSCREW HUBS

Two types have been examined, one being from a Mercedes-Benz D.B. 601A engine (Report No. 61), and the other from a Fiat A. 80R.C.41 type (Report No. 62). A summary of the details is included in Table XX.

General Features

The two hubs differed in that the German example was made as a solid component whereas the Italian part con-

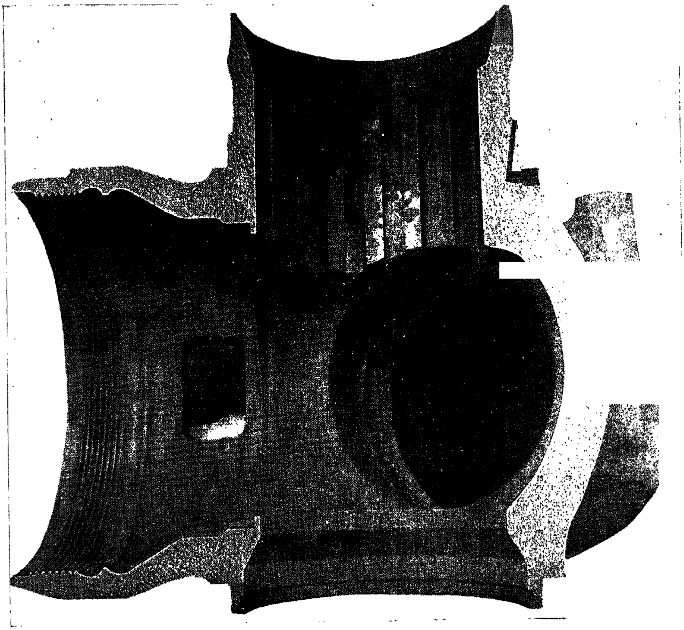


Fig. 160.—Structure of hub forging of Mercedes-Benz D.B. 601A.

Fig. 161.—Outline of airscrew hub of Fiat A. 80R.C.41.

sisted of two separate alignable parts almost identical in design, except that the centre aperture was circular in one case and hexagonal in the other.

Both hubs were cadmium-plated.

Figs. 159 and 161 illustrate the form of the parts.

Composition

The German hub was found to have been made from a 2/2 nickel-chromium-molybdenum steel, but the Italian one was a 1% chromium-molybdenum type.

Method of Manufacture

Both types of steel were representative of the basic electric-arc process, and both hubs had been made as forgings. In the case of the German one, the hub had first been made as a forged block and an axial hole had probably been punched or pierced during forging. The bulk of the metal from the interior had been removed by machining (see Fig. 160). Examination of the Italian hub showed that it had been made as two separate drop forgings to a contour closely following that of the finished article. (See Fig, 162.)

Inherent Grain Size and Cleanness

The grain sizes in both cases were medium to fine. With regard to the cleanness, while the German steel represented good-quality basic electric-arc material, the Italian steel was relatively poor.

Hardness

In both instances the hardness values were fairly uniform at approximately 300 D.H.

Microscopical Examination

Both structures indicated a hardening and tempering treatment.

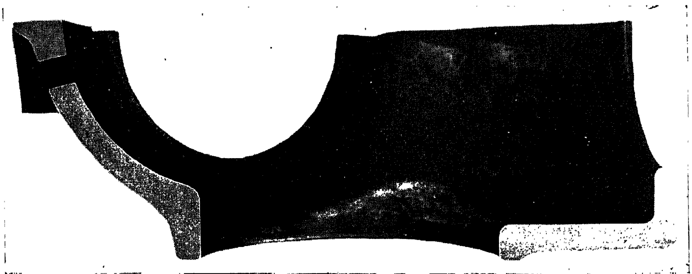


Fig. 162.—Structure of part of hub forging of Fiat A. 80R.C.41.

Section XIII—Airframe Components

A.—WELDED STEEL ENGINE MOUNTINGS

The components examined were as follows :—

(*a*) B.M.W. 132K engine (Report No. 58).

(*b*) B.M.W. 801A engine (Dornier 217E.1 aircraft) (Report No. 130).

(*c*) Bramo Fafnir 323P engine (Report No. 59).

In (*a*) and (*c*) the mountings were essentially of tubular welded steel structure comprising an engine ring, with attachments for a radial engine and struts connecting it to four points on the airframe.

The other B.M.W. mounting (*b*) did not include a ring tube, and was incomplete.

Construction

(*a*) *B.M.W. 132K Mounting.*—A general view is given in Fig. 163. The six strut tubes are attached to the tubular ring at three points, at **two of** which hollow formed or box fillets are used (see Fig. 164). Fig. 165 shows a joint of two tubes to the ring without the use of hollow fillets. Nine tubular lugs are welded longitudinally to the inside of the tubular rings to take engine bolts. The two rather massive feet at the air-frame end, to each of which two of the

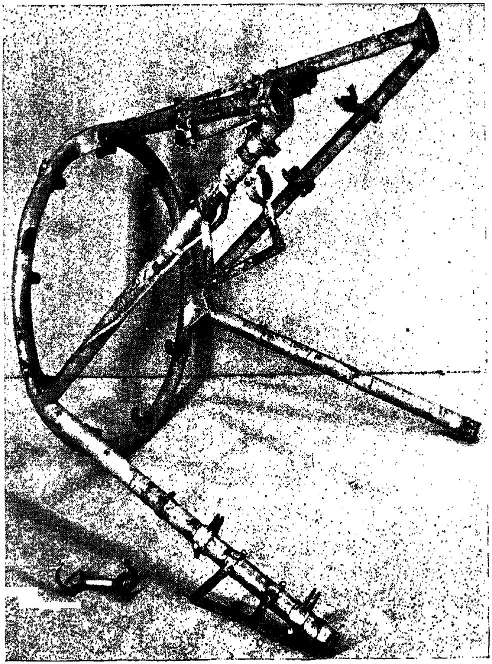


Fig. 163.—General view of B.M.W. 132K engine mounting.

struts are attached by welding, consist of a central threaded portion machined from the solid, round which the foot has been built up by welding, as shown in Fig. 166. The ring is closed by a simple butt joint.

(*b*) *B.M.W.* 801 *A*/1 *Mounting*.—A general view is shown in Fig. 167. Two portions comprise the mountings, the larger piece forming a rough M, of which the two higher points form two similar built-up feet (Figs. 168 and 169), whereas the centre point appeared to form a different type of connection (Fig. 170). In the smaller piece, the two broken strut tubes meet to form a foot similar to that shown in Fig. 168, except that the foot assembly is missing.

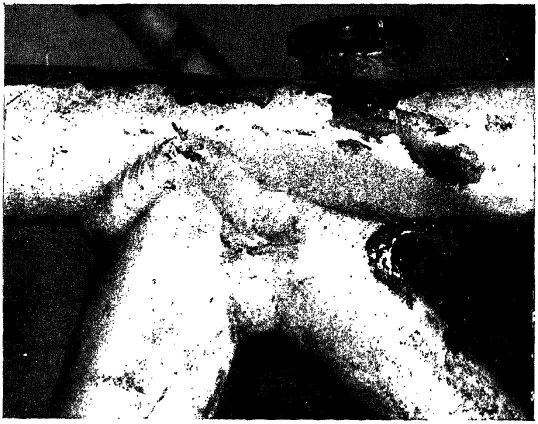


Fig. 164.—Box fillets used at two points of attachment.

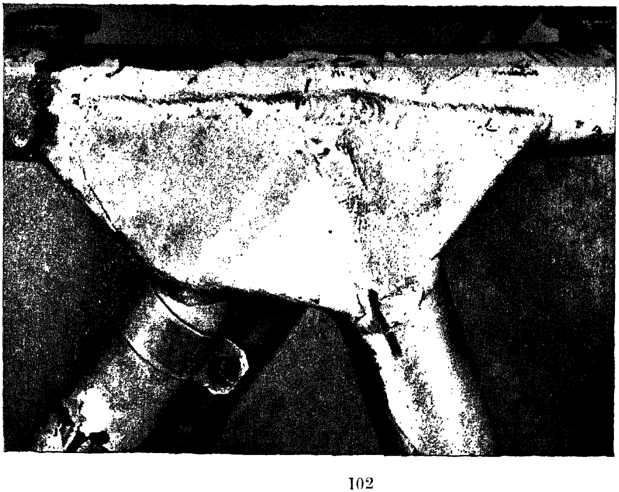


Fig. 165. A joint of two tubes without the use of box fillets.

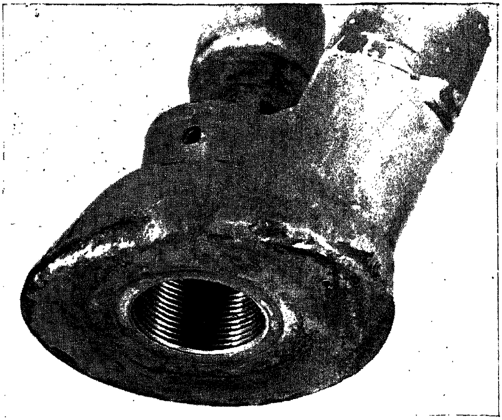


Fig. 166.—
One of the feet at the airframe end of the mounting.

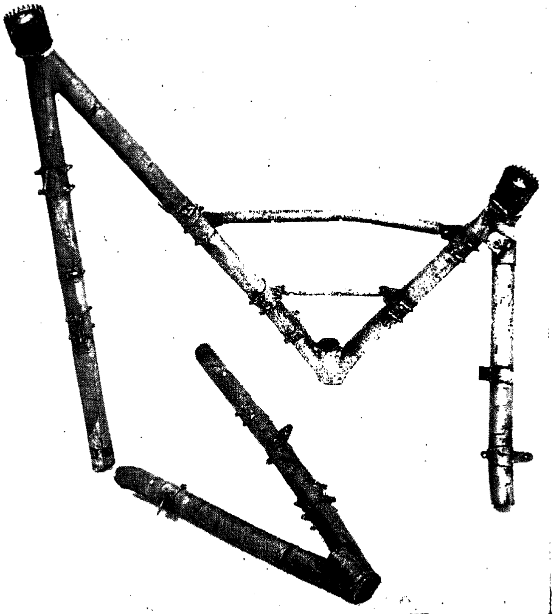


Fig. 167 -
A general view of the B.M.W. 801A/1 engine mounting.

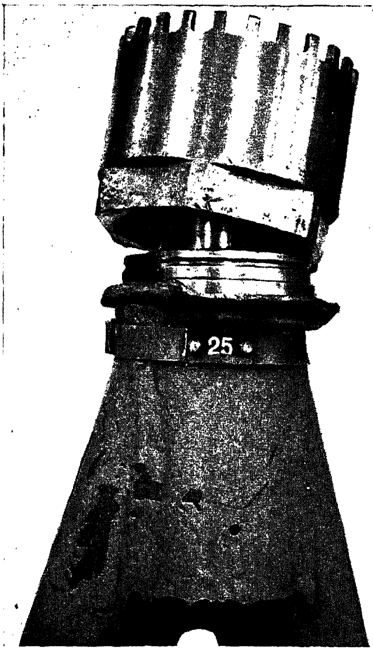
(*c*) *Bramo Fafnir* 323*P Mounting.*—A general view of the mounting is given in Fig. 171. The engine ring is connected to the airframe by eight struts which are joined in pairs at the rear, airframe end. At the engine-ring end two of the struts are joined to the ring by simple welded T-joints, but the rest of the struts meet in pairs at the ring, and at two of these multiple joints side-plates are welded on for reinforcement on both inner and outer sides of the joint. No formed fillets are used in any of these joints. Figs. 172 and 173 show joints of struts to ring without and with side-plates.

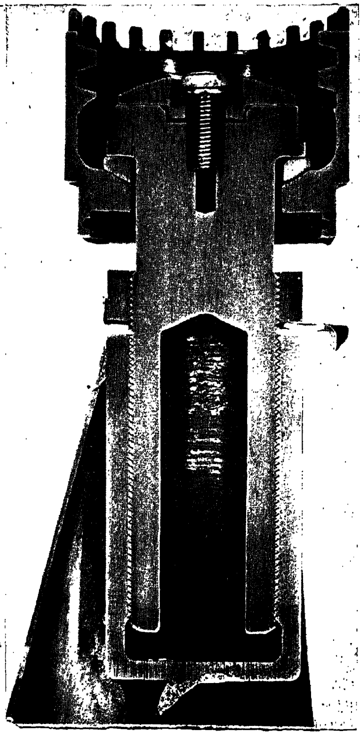
To the inside of the ring nine pairs of formed lugs are attached by welding. Each pair of lugs carries a hollow steel bolt which passes through a thick rubber bush housed in a small built-up fitting which takes the engine attachment bolts. The ring is closed by a simple butt joint.

All the feet were similar, and a photograph of one is shown in Fig. 174.

Surface Finish

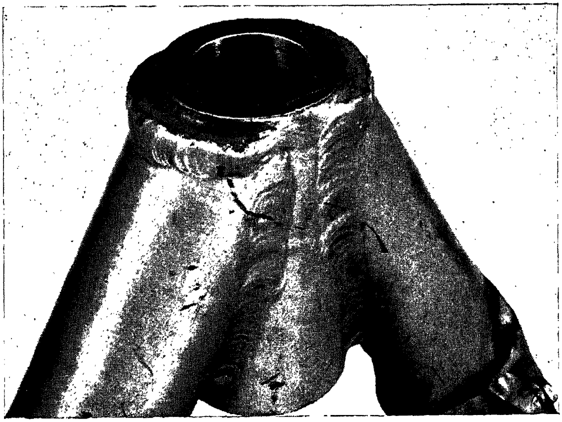
(*a*) *B.M.W.* 132 *K.*—Considerable variation of the condition of the tube surface was observed after removal of the paint. The ring tube appeared to be lightly but uniformly scaled except for local sand-blasting at the welded lugs. The strut tubes appeared to have been sand-blasted in the vicinity of the





Figs. 168 and 169.—Outline and section of one of the two similarly built feet.

Fig. 170. Outline of a different type of connection forming the mouning.



welds, but were fairly uniformly scaled elsewhere. The bore of all the welded tubes was encrusted with a heavy rust growth, but the cross-bracing tube to the strut tubes was free from internal rusting. The whole of the external surfaces are coated with a grey-green paint, and on removing this it was observed that in several places the corrosion had penetrated the tube wall.

(*b*) *B.M.W.* 801 *A*/1.—All the surfaces were painted grey-green outside, under which the surfaces both at and away from the welds were sand-blasted. The bore surfaces were lightly scaled.

(*c*) *Bramo Fafnir* 323*P*.—The whole

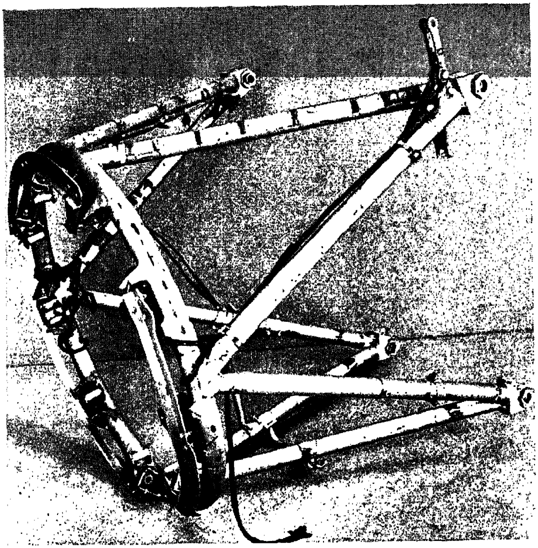


Fig. 171. General view of the Bramo Fafnir 323P. engine mounting.

of the mounting is coated with aluminium paint applied over a thick undercoat of a comparatively soft varnish. The surface of the tubes, when cleaned free of paint, had a matt appearance, and appeared to have been sand-blasted. The tubes were found to be lightly but evenly scaled in the bore.

Fig. 172.—Showing joint of strut to ring without side-plates.

General Observations

The German mountings consisted of tubes, sheet, forgings and machined parts in chromium-molybdenum steel containing about :—

	%
Carbon	0·20 to 0·28
Chromium	1·0
Molybdenum	0·20 to 0·25

The majority of the subsidiary parts such as brackets and engine bolts were made in the same steel.

The material was clean and of low sulphur content, and was probably of basic electric-arc manufacture. The inherent grain size was in the main fairly fine. The mountings were assembled by oxy-acetylene welding without subsequent heat-treatment. Micro-examination showed that the tubes were in the normalised condition prior to welding in both the B.M.W. and Bramo Fafnir mountings. The tensile strength of the tubes was of the order of 47 to 50 tons per square inch, and the ductility was reasonably good, as shown by flattening tests. Some of the welds in the complex feet of the B.M.W. 132K mounting, and

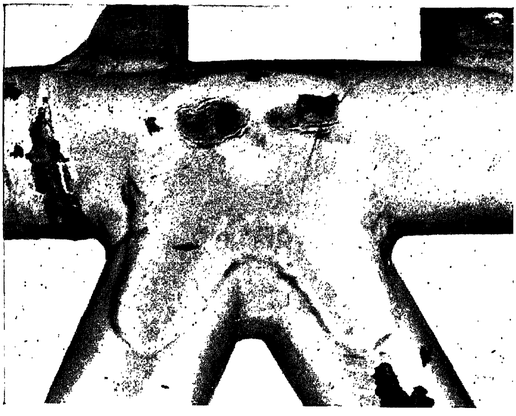


Fig. 173.—Showing joint of strut to ring with side-plates.

the welds in the bracket carrying rubber bushes, showed that these units had been normalised after welding.

The deposited metal in the welds of the German mountings was also chromium-molybdenum steel, but contained less chromium (0·75%) than the tubes. The hardness peaks, due to rapid cooling near the welds, were not severe, the highest values observed being of the order of 351. The tubular lugs carrying the engine attachment bolts on the B.M.W. 132K mounting ring, to which they are attached by fillet welds and the formed lugs on the Bramo Fafnir mounting, exemplify the important duty some of the welds have to perform in these mountings.

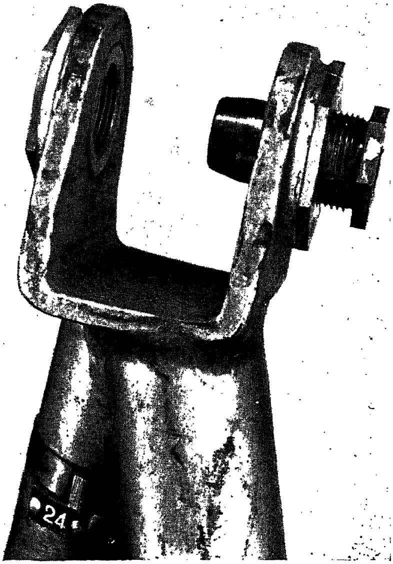


Fig. 174.—One of the feet formed on this mounting.

B.—SPAR AND RELATED COMPONENTS

These constitute the following :—

1. Centre-section spar (within fuselage)—Me 110 (Report No. 53).

2. Centre - section spar flange—Junkers 88 (V. 4GS) (Report No. 104).

3. Centre - section spar flange—Junkers 88 (4D.M.R.) (Report No. 111).

4. Top and bottom flange from centre-section spar—Me 109 (Report No. 68).

5. Strips from top and bottom spar flanges—Me 110 (Report No. 51).

Figs. 175 to 178 illustrate the appearance of the above, and Table XXI summarises the essential metallurgical details.

A brief description of each is given below :—

1. *Centre-section Spar within Fuselage* (*Fig.* 175), Me 110.—Complete details are given in the original report, with which is coupled Fig. 176.

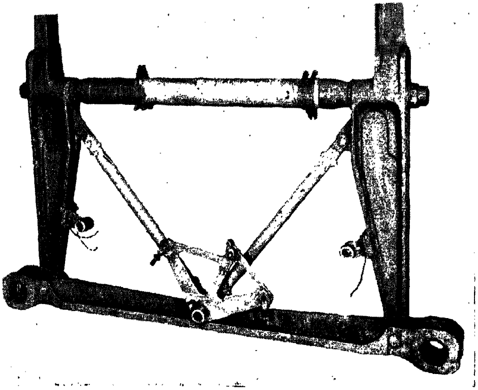
2. *Centre-section Spar Flange* (Fig. 177), *Ju* 88 (*V.* 4*GS*).—This part was about five feet long by four inches wide, and painted greyish-green. At each of the hollow ends a seating was fitted, and these had originally a smooth machined finish. The method of retaining these seatings was not apparent (see 3 below).

The threaded rings at each end of the spar were made from an anodised aluminium alloy.

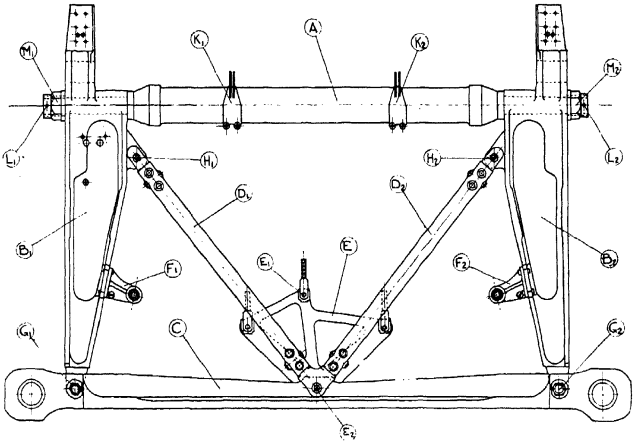
The spar also carried two ball cups, riveted as shown by light alloy rivets.

3. *Centre-section Spar Flange, Ju* 88 (4*D.M.R.*).—This was similar to the above (No. 2) except at one end it carried a collar not included with the above sample. There were no ball cups.

4. *Top and Bottom Flange from Centre-section Spar* (*Fig.* 178), *Me* 109.—Both belonged to the centre-section spar



Figs. 175 and 176.—Centre section spar within fuselage—Me 110.



of this aircraft and consisted essentially of a T-section beam with various fittings. The top flange terminated in a single boss at both ends, while the bottom flange was double. Both types contained swivel bearings.

5. *Strips from Top and Bottom Spar Flanges* (*Fig.* 179), *Me* 110.—These were portions of rectangular section strip containing a series of drill holes. Both pieces were painted grey.

Compositions

(See Table XXI.)

The majority of the steels used were of the chromium-molybdenum type with varying chromium contents and with and without vanadium, and in some cases a small nickel addition up to about 0·5%. The exceptions were under Report No. 104, where two parts had been made from 2/2 nickel chromium with molybdenum and another part

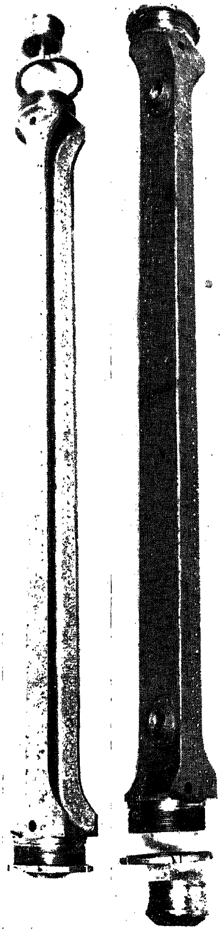


Fig. 177.—Centre section spar flange—Ju 88 (V. 4GS).

under Report No. 111, where the molybdenum content was practically nil. (See Table XXI.)

Method of Manufacture

All factors pointed to electric basic arc steel manufacture, and all components had been made from hot-worked

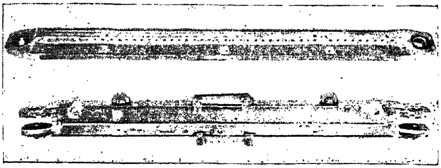


Fig. 178.—Top and bottom flange for centre-section spar—Me 109.

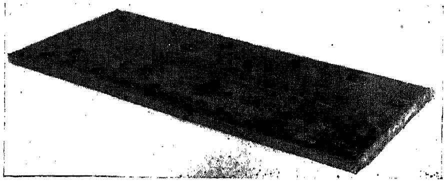


Fig. 179.—Strips for top and bottom spar flanges—Me 110.

products except in one instance, viz., part D, under Report No. 53, which was found to be a casting (see Section XI on Castings).

Cleanness

On the whole the steel used in the manufacture of these parts was of a high order of cleanness.

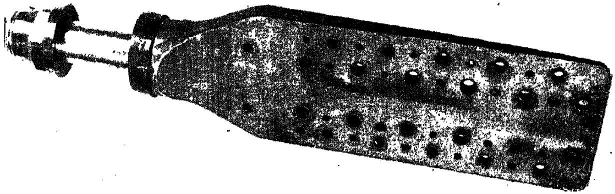
Heat-Treatment

All the parts showed hardened and tempered structures excepting the ball cups under Report No. 104. In this case the steel appeared to have been normalised.

C.—WING ROOT FITTINGS

The components investigated were :—

1. Top and bottom root fittings, Me 110 (Report No. 51).
2. Small root fitting, port wing, Me 110 (Report No. 64).
3. Top and bottom root fittings, port wing, Me 109 (Report No. 69).
4. Top and bottom root fitting, front spar, Ju 88 (V. 4GS) (Report No. 107).



Figs. 180.—Top wing root fittings—Me 110.

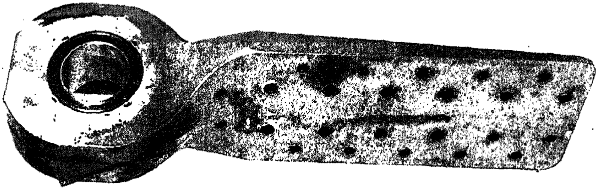


Fig. 181.—Bottom wing root fittings—Me 110.

TABLE XXI.—SPAR AND

Report No.	Type of Aircraft.	Component.	C.	Si.	Mn.	S.	P.	Ni.	Cr.	Mo.
53	Me 110	Centre Section Spar.								
		A. Tube portion........	0·25	0·29	0·60	0·005	0·011	Trace	1·03	0·21
		A. Screwed end	0·28	0·35	0·64	0·001	0·011	0·37	2·38	0·26
		B. Side member........	0·35	0·35	0·68	0·006	0·013	0·38	2·57	0·25
		C. T-section strut	0·28	0·33	0·67	0·009	0·011	0·32	2·59	0·33
		G. Bolt connecting C to B	0·24	0·28	0·61	0·006	0·017	Trace	0·94	0·23
		D1. Tubular sloping member	0·24	0·29	0·52	0·005	0·010	0·05	1·05	0·22
		D2. End forked (to B)..	0·29	0·33	0·59	0·010	0·009	0·11	2·30	0·15
		D3. V-connecting piece..	0·28	0·14	0·59	0·008	0·016	0·10	0·99	0·40
104	Ju 88 (V.4G8)	Centre Section Spar Flange.								
		Spar	0·315	0·28	0·50	0·006	0·022	2·23	2·17	0·30
		End seating............	0·32	0·32	0·41	0·010	0·012	1·90	1·94	0·36
		Ball cups	0·44	0·32	0·55	0·012	0·015	0·28	1·06	0·20
111	Ju 88 (4 DMR)	Centre Section Spar Flange.								
		Spar	0·31	0·32	0·62	0·010	0·012	0·32	2·27	0·29
		End seating............	0·32	0·33	0·73	0·013	0·014	0·10	2·48	0·03
		Collar..................	0·33	0·34	0·66	0·006	0·013	0·31	2·95	0·27
51	Me 110	Strips from top Spar Flange	0·25	0·25	0·64	0·016	0·020	0·07	0·98	0·24
68	Me 109	Centre Section Spar Flanges.								
		Top	0·28	0·38	0·64	0·007	0·020	0·37	2·59	0·29
		Swivel—Outer	1·06	0·25	0·33	0·011	0·011	—	1·41	—
		Inner	0·85	0·30	0·24	0·029	0·014	—	1·33	—
		Bottom bridge..........	0·14	0·41	1·62	0·019	0·022	—	0·09	0·04

5. Wing root fitting, Ju 88 (4D.M.R.) (Report No. 113).

6. Wing root joint fitting, Heinkel 111 (H. 6, No. F. 8 bomber) (Report No. 112).

Table XXII is a summary of the essential data obtained on these parts, while Figs. 180 to 186 illustrate their general form and dimensions.

General Description

1. *Top and Bottom Wing Root Fittings, Me 110 (Report No.* 51), *Figs.* 180 *and* 181.—Both consisted of a blade-like portion containing a number of

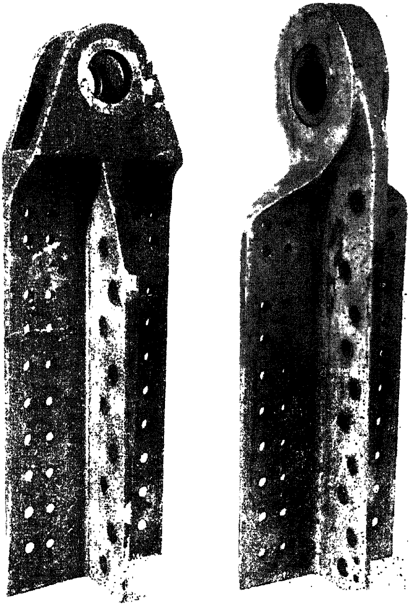


Fig. 182.—Top and bottom wing root fittings—Me 109

RELATED PARTS.

V.	Cu.	Al.	Inherent Grain Size.	YP.	MS.	El., %.	R.A., %.	Izod.	Hardness.	Special Remarks.
Nil	Trace	—	7 and 6	58·5	72·0	17·5	60·5	54, 54	315/321 B.H.	
0·17	0·12	—	Fine	68·2	73·5	19·5	58	39, 38	344/348 B.H.	
0·17	0·11	—	Fine	64·8	72·5	20	62	44, 45, 46	321/364 B.H.	
Nil	0·07	—	5	67·1	74·1	20·5	62	52, 52, 55	357/372 B.H.	
Nil	0·11	—	5	55·0	60·2	22·5	65·5	—	295/306 B.H.	
Nil	0·06	—	6	58·4	63·2	18·5	—	—	293/302 B.H.	
0·18	0·14	—	6	69·5	77·6	24	66	—	387/418 B.H.	
Nil	0·17	—	4 to 6	45·9	52·9	24	67	—	269 B.H.	Casting
0·12	0·12	0·02	4	—	82·3	16 9	50·5	15, 17, 13	364/375 B.H.	Structure coarse and overheated.
Nil	—	—	—	—	—	—	—	—	375/400 D.H.	
—	—	—	—	—	—	—	—	—	193/203 D.H.	
0·22	—	—	7	—	73·6	20·0	65	58, 58, 58	332–340	
0·22	—	—	6	—	—	—	—	—	302	
0·19	—	—	7	—	—	—	—	—	—	
Nil	0·13	—	6	52·1	57·8	20	53	—	285 B.H.	Bottom—similar
Nil	—	—	5 to 6	77·0	83·2	16·5	55	29 approx.	388/401 B.H.	Bottom—similar
—	—	—	4 to 5	—	—	—	—	–	383/411 B.H.	
—	—	—	4 to 5	—	—	—	—	—	769/798 B.H.	
—	—	—	7 to 8 (some 5)	—	—	—	—	—	197/207 B.H.	

drilled holes. The top fitting terminated with a spindle and screwed portion, while the bottom fitting had a seating containing a swivel bearing. Both were painted grey, except the ends already mentioned.

2. *Small Wing Root Fitting, Me* 110 (*Report No.* 64).—This merely consisted of two forked portions held together by a hexagonal nut. The exposed surfaces were covered with grey paint over an oxidised finish.

3. *Top and Bottom Wing Root Fittings, Me* 109 (*Report No.* 69), *Fig.* 182.—The top fitting was a T-section forging one end of which was connected with a forked portion parallel to the top of the T and containing holes for the spindle. The bottom component was somewhat similar, except that the end of the T-section connected with a flat cylindrical portion at right angles to the top of the T and carrying a spherical seated

TABLE XXII.—WING

Report No.	Type of Aircraft.	Component.	C.	Si.	Mn.	S.	P.	Ni.	Cr.	Mo.
51	Me 110	Wing Root Fitting.								
		Top—Blade	0·32	0·31	0·72	0·005	0·007	0·59	2·12	0·30
		Nut	0·25	0·29	0·68	0·007	0·012	0·06	1·02	0·19
		Washer	0·29	0·17	0·63	0·011	0·009	0·08	2·53	0·20
		Bottom—Swivel (Outer)	1·04	0·32	0·33	0·004	0·008	0·15	1·51	0·06
64	Me 110	Small Root Fitting.								
		Large fork	0·21	0·28	0·57	0·010	0·010	0·13	0·96	0·20
		Small fork	0·29	0·17	0·59	0·013	0·012	0·09	2·48	0·21
		Nut	0·33	0·27	0·70	0·005	0·009	0·36	2·51	0·25
69	Me 109	Wing Root Fitting.								
		Top	0·30	0·31	0·58	0·004	0·006	0·11	2·62	0·43
		Bottom	0·24	0·23	0·56	0·007	0·011	0·05	0·97	0·19
		Swivel joint (outer)	1·01	0·27	0·27	0·027	0·018	<0·02	1·40	Trace
107	Ju 88 (V. 4GS)	Wing Root Fitting.								
		Top—Fork	0·29	0·27	0·54	0·013	0·020	0·01	2·55	0·27
		Collar	0·33	0·31	0·42	0·006	0·009	1·93	2·02	0·32
113	Ju 88 (4 DMR)	Wing Root Fitting	0·31	0·35	0·70	0·010	0·015	0·21	2·40	0·27
112	Heinkel 111-H6	Wing Root Joint Fitting.								
		1. Casting	0·23	0·10	0·66	0·008	0·012	0·05	0·93	0·14
		2. Seating	0·35	0·27	0·66	0·008	0·009	0·19	2·36	Nil
		3. Nut	0·30	0·25	0·59	0·008	0·017	0·27	2·39	0·33
		4. Collar	0·28	0·34	0·37	0·008	0·008	1·86	1·90	0·27
		5. Tube	0·23	0·20	0·61	0·010	0·011	0·14	1·01	0·16
		5a. Fin (thin)	0·26	—	0·60	—	—	—	0·99	0·13
		5b. Fin (thick)	0·27	—	1·08	—	—	—	0·67	Nil
		5c. Fin	—	0·29	0·62	—	—	0·17	1·10	0·19
		5d. Weld metal 1	—	0·30/ 0·43	0·55/ 0·62	—	—	0·16/ 0·28	1·07/ 1·18	0·19/ 0·39
		5e. Weld metal 2	—	0·29/ 0·41	0·75/ 0·78	—	—	0·20/ 0·24	1·14/ 1·22	Nil
		6. Internal screwed member	0·32	0·27	0·48	0·010	0·011	1·61	2·46	0·33
		7. Pin (through end of 5)	0·23	0·25	0·55	—	—	3·13	0·79	Nil
		8. Washer (on bolt 10)	Dead	mild	steel	(carbo	n less	than	0·1%)	
		9. Pin (through ball joint)	0·26	0·30	0·58	0·010	0·007	0·12	0·98	0·10
		10. Bolt (connecting two portions of ball joint)	0·28	0·29	0·71	—	—	0·06	1·00	0·14
		11. [illegible] 5)	Carbo	n steel	(about	0·6%	carbo	n)		
		12. [illegible]	0·19	0·17	0·69	0·208	—	0·02	0·03	Nil
		13. Hemispherical bearing	0·31	0·26	0·49	0·010	0·012	1·62	2·45	0·36

swivel bearing. Both parts had smooth surfaces covered with grey paint.

4. *Top and Bottom Root Fittings* (*Ju* 88) (*Report No.* 107), *Fig.* 183.—These were very similar in design, the differences being only slight ones of dimensions. They consisted of two parts, one a forked member provided with a spherical seating at one end, on which was fitted a collar with an internal screw thread and spherical surface moving over the spherical seating of the forked member. The fittings were painted grey over a cadmium-plated surface.

5. *Wing Root Fitting, Ju* 88 (*Report No.* 113).—This was similar to Report No. 107 above, the only essential difference being that the present one was zinc-plated and not cadmium-plated.

6. *Wing Root Joint Fitting, **He** 111* (*Report No.* 112), *Fig.* 184.—The

ROOT COMPONENTS.

V.	Cu.	Grain Size.	Y.P.	M.S.	E. %.	R.A. %.	Izod.	Brinell Hardness.	Special Remarks.
0·12	Trace	6 to 7	71·9	77·8	20	60	46, 53	375/402	Bottom similar
Nil	0·13	6 to 7	—	—	—	—	—	311	
0·18	0·16	6	—	—	—	—	—	340/364	
Nil	0·12	7	—	—	—	—	—	256/257 (outer) 471/475 (inner)	Inner similar
Nil	0·13	7	58·2	61·0	17	61·5	—	302–311	
0·20	0·13	7 to 8	71·6	74·7	17	61·5	—	369–375	
0·17	0·09	Fine	—	—	—	—	—	364–375	
0·28	0·15	Fine	72·9	75·6	6 (B.O.P.)	57·5	31	364/418	
Nil	0·13	5 (some 3 and 4 grains)	74·0	77·8	14 (B.O.P.)	52·5	28	375/387	
Nil	0·10	Fine	—	—	—	—	—	286/293 (outer) 504/512 (inner)	Inner similar
0·33	0·17	About 7	51·2	58·4	21	65·5	71, 64, 71	283/302	Bottom wing root fitting similar
Nil	0·08	6 to 7	76·6	80·9	17	57	—	356/364	
0·15	0·15	—	—	—	—	—	—	302/336	
Nil	0·11	Mainly 1–2 and 5	53·7	56·9	20	54	—	255–269	
0·19	0·11	Probably fine	50·5	55·5	20	66	—	288–317	
								296–300	
								302–309	
0·22	0·12	8 or finer	72·0	77·5	16·5	43·5	—	358–387	
Nil	0·09	6 and 7	69·0	74·5	15	52	—	351–364	
								358–354	
Nil	0·07	4 to 5	53·6	64·0	21.5	61·5	—	319, 327	
Nil	—	—	—	—	—	—	—	329–337	
0·13	—	—	—	—	—	—	—	319–325	
Nil	—	—	—	—	—	—	—	341–345	
Nil	—	—	—	—	—	—	—	—	
Trace	—	—	—	—	—	—	—	—	
Trace	0·07	6 to 7	68·0	78·5	17·5	62	–	350–404, 358	
Nil	0·12	3 to 6	—	—	—	—	—	280–282	
—	—	—	—	—	—	—	—	187–192	
Nil	0·09	6 to 7	—	—	—	—	—	288–296	
Nil	0·13	3 and 4	—	—	—	—	—	293–296	
—	—	—	—	—	—	—	—	415–421	
Nil	0·05	Probably fine	38·3	43·3	17	42½	—	207–208	
Trace	0·09	6	—	—	—	—	—	363–368	

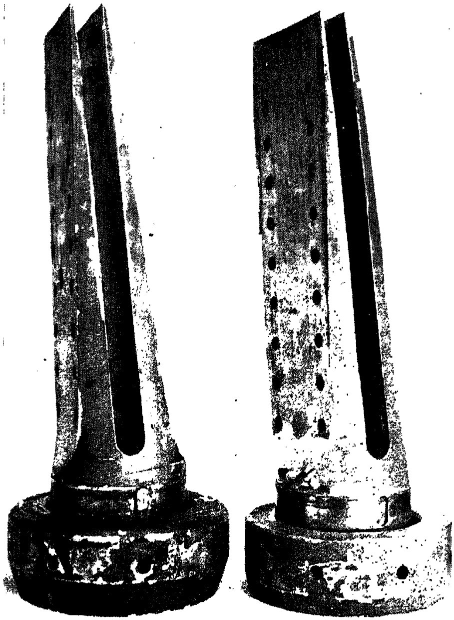


Fig. 183.—Top and bottom wing root fittings—Ju 88.

(1) Wing root fittings (Me 110) — made as forgings.
(2) Small root fitting (Me 110) — small fork machined from bar, large fork machined as forging.
(3) Wing root fitting (Me 109) — made as forgings.
(4) Wing root fittings (Ju 88) (V. 4G.S.) — made as forgings.
(5) Wing root fitting (Ju 88) (4D.M.R.) — made as forgings.
(6) Wing root joint fitting (Heinkel 111) — this component consisted of 13 parts, which are detailed in Table XXII. All parts but one were hot-worked products, and will not be discussed further. The other part (No. 1) was a good-quality casting (see Section X).

component consisted of two portions connected by a swivel joint, and there were 13 parts in all (see Fig. 184). The whole exterior of the component and the interior of the tubular part were painted.

Composition

The analyses were variable, but were mostly of the chromium-molybdenum class with or without vanadium. A few of the minor parts were nickel-chromium-molybdenum type.

Method of Manufacture

The bulk of the material used for these parts was considered to be of basic electric-arc manufacture. The subsequent procedure in making the parts was as follows :—

Cleanness

Most of the parts examined had a high order of cleanness.

Heat-Treatment

With the exception of the outer swivels, under Reports Nos. 51 and 69, all components were in the hardened and tempered condition.

Special Remarks

Generally speaking, the parts examined were of a high standard. The wing root fitting from a Junkers 88 (4D.M.R.) (Report No. 113), was in the nature of a check examination of similar fittings from a Junkers 88 (V. 4G.S.) aircraft reported earlier (Report No. 107). No deterioration in quality was

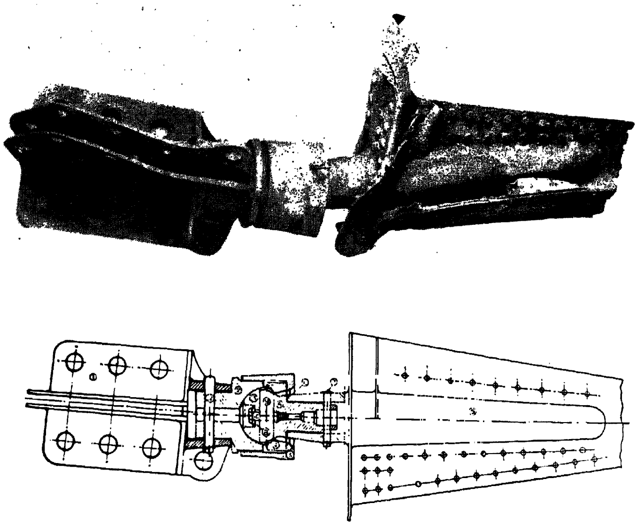


Fig. 184.—Wing root joint fitting—He 111.

observed except that the recent sample was zinc-coated and not cadmium-coated as previously.

D.—PARTS OF UNDERCARRIAGES

The undercarriage parts examined were as follows :—

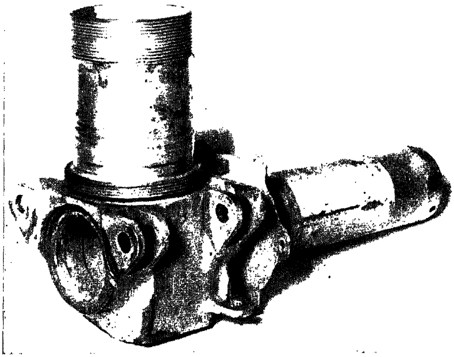
1. From a Junkers Ju 88 aircraft.
   (*a*) Axle, knee-piece (Report No. 26), Fig. 185.
   (*b*) Torsion link (Report No. 25), Fig. 186.
2. From a Messerschmitt Me 110 aircraft.
   (*a*) Main undercarriage strut (Report No. 49), Figs. 188, 189 and 190.
   (*b*) Tail wheel assembly (Report No. 50), Figs. 191 and 192.
3. From a Messerschmitt Me 109 aircraft.
   (*a*) Main undercarriage strut (Report No. 65), Fig. 193.
   (*b*) Tail wheel assembly (Report No. 67), Figs. 194, 195 and 196.
   (*c*) Undercarriage bracket (Report No. 66), Fig. 198.

The items before being dismantled are shown in the attached photographs. In certain cases photographs have been included after dismantling.

Table XXIII gives a summary of the essential details of each. For fuller details see Section X.

In the Ju 88 aircraft the knee-piece, which also formed the lower end of the shock absorber strut, was found to be a steel casting made in 0·23% carbon, 1% chromium, 0·25% molybdenum steel heat-treated to a tensile strength of 70 tons per sq. in. Castings of a similar type have been employed on the Me 110 and Me 109 main undercarriage struts.

The axle in the Ju 88 fitting was a separate component, being held in by keys ; but in the Me 109 and Me 110 fittings it was part of the casting. The torsion links and the head of the Me 109 strut also were steel castings. A full



description of the properties of all these castings is given in Section X.

The axle in the Ju 88 fitting was made from a drawn tube of chromium-molybdenum steel containing 0·25% carbon, 1·03% chromium, and 0·24% molybdenum. A tensile test on a specimen from the axle gave

Fig. 185.—Axle knee-piece and shock absorber strut — Ju 88.

TABLE XXIII.—UNDERCARRIAGE COMPONENTS.

Report No.	Type of Aircraft.	Component.	C.	Si.	Mn.	S.	P.	Ni.	Cr.
26	Junkers 88	Undercarriage Assembly.							
		Shock absorber strut	0·23	0·45	0·64	0·004	0·005	0·02	0·94
		Knee-piece	—	—	—	—	—	—	—
		Axle	0·25	0·19	0·50	0·011	0·022	0·02	1·03
		Tube from inside axle	0·04	Trace	0·42	0·033	0·061	Nil	0·03
		Steel key	0·37	0·29	0·66	0·010	0·015	0·22	1·01
25	Junkers 88	Torsion link	0·43	0·25	0·53	0·023	0·013	0·12	1·12
		Torsion link—Steel bush	0·28	0·22	0·53	0·009	0·009	0·02	1·11
49	Me 110	Main Undercarriage Strut and Axle.							
		Plunger tube	0·25	0·38	0·45	0·011	0·008	0·10	2·53
		Cylinder tube	0·25	0·31	0·41	0·010	0·017	0·24	0·99
		Torsion link	0·26	0·235	0·60	0·007	0·014	0·29	1·01
		Axle } Single casting	0·26	0·39	0·64	0·004	0·010	0·14	0·98
		Knee-piece } Single casting	0·26	0·39	0·64	0·004	0·010	0·14	0·98
		Radial support	0·29	0·34	0·62	0·005	0·011	0·31	2·37
		Retraction arm	0·26	0·37	0·66	0·009	0·012	0·11	0·98
		Retraction bracket	0·29	0·33	0·71	0·005	0·013	0·09	0·89
50	Me 110	Tail Wheel Assembly—Barrel Portion.							
		Outer barrel	0·26	0·28	0·50	0·011	0·009	0·02	1·04
		Weld metal	—	0·28	0·56	—	—	0·06	0·84
		Registering unit steel pin	0·28	0·23	0·55	0·009	0·009	2·22	1·82
		Flanged end-plate	0·32	0·28	0·68	0·011	0·010	0·32	2·32
		Two setscrews (A.8)	—	0·15	0·52	—	—	0·02	2·60
		Two setscrews (A10)	0·09	0·01	0·72	—	—	0·02	0·08

values of 52·4 tons/sq. in. and 66·0 tons/sq. in. for 0·1% proof and maximum stress, with 11·5% elongation on 2 in. This axle had been zinc-coated. The axle on the Me 110 had been chromium-plated, but no surface treatment had been applied to the Me 109 axle.

The torsion link from the Ju 88 was a drop stamping in steel of the 0·4% carbon, 1% chromium, 0·25% molybdenum type heat-treated to give 0·1% proof stress and maximum stress values of 37·2 and 51·2 tons/sq. in., with 19% elongation on 2 in. The links from the Me 110 were also made of chromium-molybdenum steel, but with only 0·26% carbon. The tensile properties were, however, better than those obtained on the

Fig. 186.—Torsion link—Ju 88.

Continued on pages 120-121.

Mo.	V.	Cu.	Al.	Y.P.	M.S.	El., %.	R.A., %.	Izod.	Hardness.	Special Remarks.
0·25	Nil	0·10	Ti., 0·003	66·4	72·2	7 (on 2")	—	—	—	Single casting
—	—	—	Al., 0·063	67·9	69·5	3 (on 2·4")	—	—	—	Single casting
0·24	Nil	0·10	—	60·0	66·0	11·5 (on 2")	—	—	—	H. and T.
0·02	Nil	0·01	—	—	—	—	—	—	124/132	Hot-rolled
0·23	Nil	0·10	—	—	—	—	—	—	287/315 B.H.	Cold-worked
0·22	Nil	0·19	—	41·2	51·2	19 (on 2")	—	—	—	H. and T.
0·24	Nil	0·10	—	—	88 app'x.	—	—	—	—	H. and T.
0·27	0·25	—	—	—	78	22	61	—	354 (Steel) 642 (Cr. plate max.)	Chromium-plated H. and T.
0·24	—	—	—	—	73·5	17·5	53·5	36·5	284/351	H. and T.
0·19	—	—	—	—	68·5	22	62·3	—	318/337	Normalised.
0·20	—	—	—	—	75·0	8	25·5	—	673 max. Cr. plate 337/354 (Steel)	Chromium-plated, H. and T. cast
0 20	—	—	—	—	77·0	9	25	—	673 max. Cr. plate 366 (Steel)	H. and T. casting
0·26	0·15	—	—	—	87·0	18·5	56·7	—	396/412	Normalised
0·22	—	—	—	—	—	—	—	—	318/325	Normalised
0·18	—	—	—	—	—	—	—	—	324/336	H. and T. casting
0·24	Nil	—	—	—	—	—	—	—	302/321	Four bosses welded to end of barrel and two spindle bosses welded to barrel approx. similar. Two bosses welded to side of barrel—one 1% Cr-Mo, and the other 0·44% C steel (228 VDH).
0·26	—	—	—	—	—	—	—	—	—	
0·31	0·23	—	—	—	—	—	—	—	341	
0·22	0·18	—	—	—	—	—	—	—	364/387	
0·34	Nil	—	—	—	—	—	—	—	321/363	Two set-screws A.9 similar (all set-screws Cd. plated).
—	—	—	—	—	—	—	—	—	212/229	Six set-screws A.11 approx. similar (all set-screws Cd. plated).

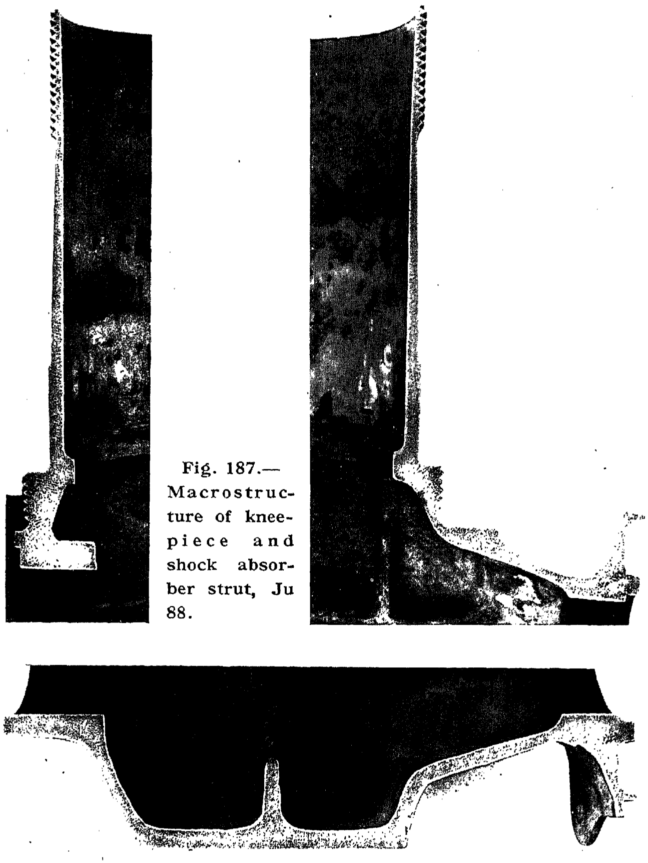


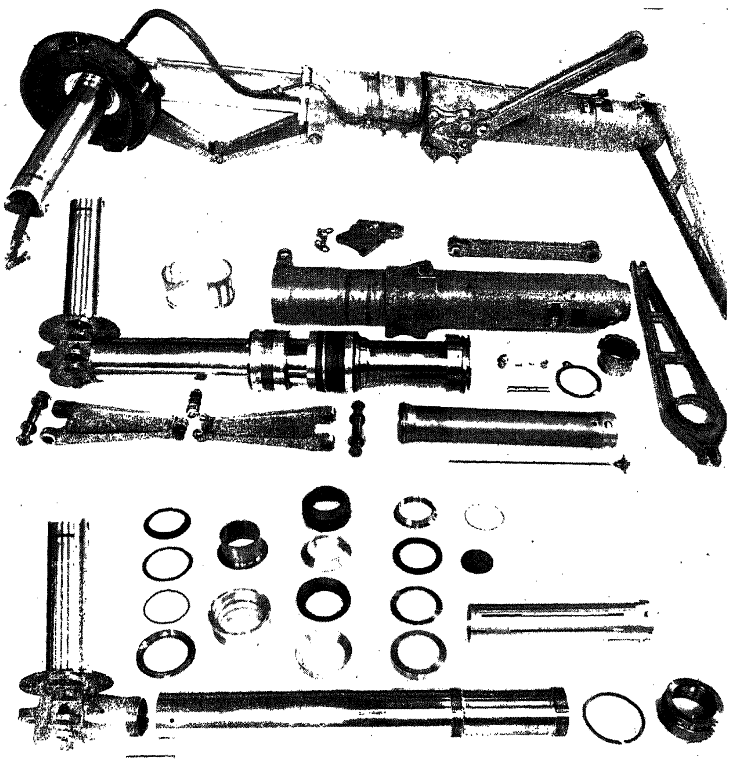
Fig. 187.—Macrostructure of knee-piece and shock absorber strut, Ju 88.

Ju 88 link, being 68·5 tons per sq. in. maximum stress with 22% elongation (on $4\sqrt{A}$.)

The main undercarriage struts of the Me 110 and Me 109 have been completely dismantled and the properties of all the components determined. The number of parts involved is very large, and it is not intended to enter into a full description in this publication. It was found, however, that the majority of the steel parts had been made of steel of the 1% chromium, ¼% molybdenum type, with carbon contents ranging from 0·2% to 0·5%.

The tensile strength values ranged from 61 to 73 tons per sq. in., with a normal degree of ductility.

Exceptions to the above were the plunger tubes on both struts and the radial support on the Me 110 strut.



Figs. 188, 189 and 190.—Main undercarriage strut—Me 110.

These three components were made in steel containing 0·25 to 0·30% carbon, 2·5% chromium, 0·25% molybdenum, and 0·15 to 0·28% vanadium. The tensile strengths varied from 78 to 87 tons per sq. in., and the elongation values from 16 to 22% on $4\sqrt{A}$.

The plunger tubes on both struts had been chromium-plated. On the Me 110 tube the thickness of chromium was 0·005 in. On the Me 109 tube the thickness was only 0·0016, and a very thin undercoating of nickel was present.

The chromium coatings had a fine lapped finish, and diamond pyramid hardness tests gave values of 642 (10 kg. load) for the Me 110 tube and approximately 840 (0·5 kg. load) for the Me 109 tube.

The tail wheel assemblies from the Me 110 and Me 109 aircraft have also been completely dismantled and investigated, but only the major components will be described here. It was found that with few exceptions the steel parts consisted of chrome-molybdenum steel, although the compositions show considerable variation.

In the Me 110 fitting the fork had been built up by welding together sheet material in chromium-molybdenum steel containing 0·26% carbon, 0·95%

chromium, and 0·22% molybdenum. Welding rod of similar alloy content had been used. The fork had been welded to the sliding tube, which had been machined from bar of similar chemical composition to that of the fork, and the tube and fork combined had been heat-treated after welding to a tensile strength of approximately 74 tons per sq. in.

In the Me 109 fitting the fork was a casting in chromium-molybdenum steel of the usual type. The part had been hardened and tempered to a tensile strength of 60 tons/sq. in., and was bolted to the sliding tube. The tube had been machined from a bar of chromium-molybdenum-vanadium steel similar in type to that used for the tubes in the undercarriage struts, and hardened and tempered to give tensile properties of the same order.

The main cylinders of both units were made in chromium-molybdenum steel, but whereas the one from the Me 110 had been heat-treated to a tensile strength of 70 tons/sq. in., that from the Me 109 possessed a tensile strength of only 47·2 tons/sq. in. A similar difference in tensile properties was found in the inner sleeves in the two components. In the Me 110 the part was made from 2% chromium-molybdenum - vanadium steel, and possessed a tensile strength of about 66 tons/sq. in. In the Me 109 unit it was made in the usual chromium molybdenum steel and possessed a tensile strength of only 43 tons/sq. in.

TABLE XXIII. *contd.*—UNDER-

Report No.	Type of Aircraft.	Component.	C.	Si.	Mn.	S.	P.	Ni.	Cr.
65	Me 109	Undercarriage Strut.							
		Head	0·26	0·40	0·72	0·011	0·015	0·20	0·83
		Top cylinder	0·49	0·32	0·59	0·015	0·032	Nil	1·13
		Collar	0·26	0·22	0·58	0·012	0·010	0·03	1·02
		Bottom cylinder	0·41	0·29	0·56	0·014	0·024	0·05	1·16
		Torsion links (Upper)	0·23	0·44	0·66	0·018	0·010	0·12	0·86
		Foot	0·19	0·49	0·65	0·014	0·012	0·11	0·89
		Bearing bush (Outer)	—	0·30	0·81	0·026	0·020	0·30	1·01
		Bearing bush (Inner)	—	0·24	0·38	0·026	0·035	0·05	0·19
		Separator bush	0·27	0·29	0·56	0·017	0·015	0·06	0·99
		Piston	0·30	0·36	0·49	0·011	0·012	0·25	2·42
		Screw cap	0·32	0·24	0·49	0·01	0·01	1·92	1·92
66	Me 109	Undercarriage Bracket (Port).							
		Bracket casting	0·25	0·42	0·69	0·009	0·012	0·08	0·98
		Fittings—							
		Pivot spindle	0·30	0·36	0·59	0·009	0·006	1·92	1·83
		Connecting link	0·28	0·31	0·55	0·013	0·013	0·04	1·07
		Connecting link pin	0·34	0·27	0·46	—	—	1·73	2·00
		Coupling jaw	0·32	0·38	0·71	—	—	0·06	2·56
		Coupling pin	0·32	0·24	0·60	—	—	0·08	2·64
		Coupling pin spherical sleeve	1·05	0·34	0·32	—	—	0·12	1·63
		Coupling inner spherical bush	—	0·32	0·31	—	—	0·10	1·54
		Coupling outer spherical bush	—	0·27	0·64	—	—	Trace	0·21
		Catch [illegible]	—	0·32	1·08	—	—	0·05	1·18
		Insert [illegible]	0·18	0·24	0·93	—	—	0·09	1·17

Report No.	Type of Aircraft.	Component.	C.	Si.	Mn.	S.	P.	Ni.	Cr.
67	Me 109	Tail Wheel Assembly.							
		Main cylinder	0·27	0·20	0·63	—	—	0·16	1·03
		Horse-shoe wheel mounting	0·23	0·44	0·60	—	—	0·07	1·12
		Hollow ram	0·43	0·27	0·48	—	—	0·11	1·70
		Main-spring	0·66	2·87	0·84	0·016	0·017	0·02	0·01
		Stationary sleeve	0·30	0·27	0·72	0·010	0·017	0·11	1·12

The main and auxiliary springs in the Me 110 unit and the main spring in the Me 109 unit were all made in silico-manganese steel containing:—

	%
Carbon	0·57 to 0·66
Silicon..................	2·60 to 2·87
Manganese	0·82 to 0·84

The springs had a diamond hardness ranging from 550 to 636. Surface decarburisation was present in the Me 109 spring, and the ends of both springs from the Me 110 had been softened to about 300 D.H. The surfaces of the springs had apparently been sand-blasted, and the springs appeared to have been cold-coiled from cold-drawn wire and then hardened and tempered.

The Me 109 undercarriage bracket (Report No. 66) consisted in the main of a 1% chromium-molybdenum steel casting with many subsidiary fittings of various analyses, details of which will be found in Section X. The casting, apart from two relatively unimportant defects, was sound and had been ground and/or machined over the whole of the accessible surface (see Figs. 197 and 198).

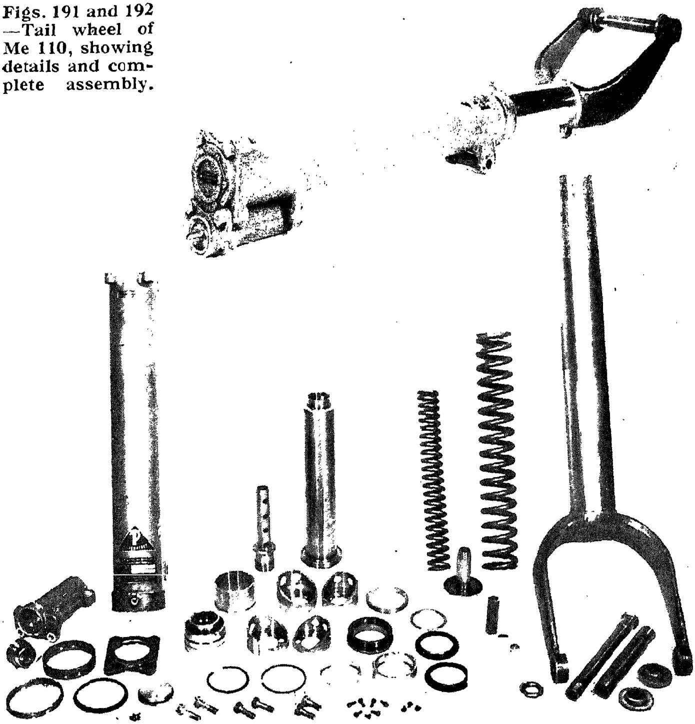
With the exceptions of the main cylinder of the Me 109 undercarriage strut and the inner cylinder of the Me 110 tail assembly, all the main parts were made in high-quality basic electric-furnace steel. In one or two of the basic electric steel parts the standard of cleanness was rather low. In general however, the steels were very clean.

CARRIAGE COMPONENTS.

Mo.	V.	Cu.	Al.	Y.P.	M.S.	El., %.	R.A., %.	Izod.	Hardness.	Special Remarks.
0·13	Nil	0·18	0·08	—	61·0	14·0	46	34, 38	—	Casting
0·20	Nil	0·04	0·06	—	66·4	16·0	34·9	—	—	
0·26	—	—	—	—	—	—	—	—	322 D.H.	
0·23	Nil	0·14	0·02	—	61·5	21·2	50·8	—	—	
0·18	0·05	—	—	—	67·0	16·5	35·0	47, 51	—	Casting lower approx. similar
0·24	0·05	0·18	0·02	—	52·6	17·5	43·4	70	—	Casting
0·32	—	—	—	—	—	—	—	—	825 D.H. (Case) 363 D.H. (Core)	Carburised inside and outside
Nil	—	—	—	—	—	—	—	—	847 D.H. (Case) 220 D.H. (Core)	Carburised outside only
0·20	—	—	—	—	—	—	—	—	214 D.H.	
0·23	0·28	—	—	—	84·5	16·7	37·3	—	—	Chromium-plated
0·19	—	—	—	—	—	—	—	—	388 D.H.	
0·12	Nil	0·10	0·08	61·2	66·1	12·8	—	—	—	
0·21	0·13	—	—	—	—	—	—	49	302/332 B.H.	
0·22	Nil	—	—	—	—	—	—	—	302/331 B.H.	Coupling jaw bush, coupling nut, and coupling pin nut approx. similar
0·35	Nil	—	—	—	—	—	—	—	352/363 B.H.	
0·28	0·26	—	—	—	—	—	—	—	430/444	
0·31	0·33	—	—	—	—	—	—	—	351	
0·12	Nil	—	—	—	—	—	—	—	798/819 D.H.	
Nil	Nil	—	—	—	—	—	—	—	810/822 D.H.	
—	—	—	—	—	—	—	—	—	242/258 D.H.	
0·27	Nil	—	—	—	—	—	—	—	303/315 D.H.	
0·25	Nil	—	—	—	—	—	—	—	302/311 D.H. (Core) 823/890 D.H. (Case)	Carburised

Mo.	V.	Cu.	Al.	Inh'nt. Grain Size.	Y.P.	M.S.	El., %.	R.A., %.	Izod.	Hardness.	Special Remarks.
0·31	—	—		6–8	39·7	47·2	32·9	—	—	239/249 D.H.	
0·28	—	—		5–7	50·0	59·5	25·0	37·2	—	270/280 D.H.	Casting
0·30	0·18	—		5–6	66·1	74·1	20·0	—	—	350/360 D.H.	
—	—	—		—	—	—	—	—	—	636 D.H.	
0·23	—	—		4–6	31·6	43·23	35·5	—	—	224/230 D.H.	

Figs. 191 and 192 —Tail wheel of Me 110, showing details and complete assembly.



E.—PARTS OF CONTROL SYSTEMS

The following parts were examined :—

1. Main lead from control column — Me 110 (Report No. 55).
2. Control rod operating elevator tabs — Me 110 (Report No. 55).
3. Flap control tube — Me 109 (Report No. 70).
4. Flap control tube — Junkers 88 (4 D.M.R.) (Report No. 113).
5. Control rod (fuselage) — Junkers 88 (V. 4G.S.) (Report No. 107).
6. Auxiliary control column — Junkers 88 (V. 4G.S.) (Report No. 105).
7. Part of steel tube operating driving brake, Junkers 88 (V. 4G.S.) (Report No. 108).
8. Tail plane incidence adjustment crank, Junkers 88 (V. 4G.S.) (Report No. 108).
9. Rudder control wire — Me 109 (Report No. 71).
10. Spring (inside bomb door control tube) — Junkers 88 (Report No. 109).

These parts are illustrated in Figs. 199 to 210. Some of the components were non-ferrous types and have not been considered in this report. In addition, several components were composed of a multitude of small parts, so that for the purposes of this report only the major parts are dealt with. A more detailed list will, however, be found in Table XXIV.

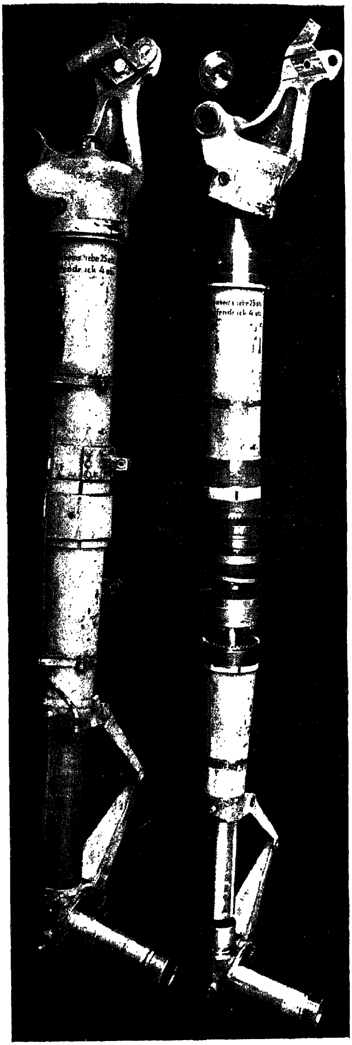


Fig. 193. Main undercarriage strut—Me 109.

A general description of the various components is as follows :—

1. *Main Lead from Control Column* (*Fig.* 199).—This consisted of a solid-drawn tube 14 mm. dia. reduced at the ends to 10 mm. dia. An 8 mm. dia. plain insert was fitted into one end, and into the other was fixed a screw carrying a square non-ferrous nut. The tubular portion was grey painted.

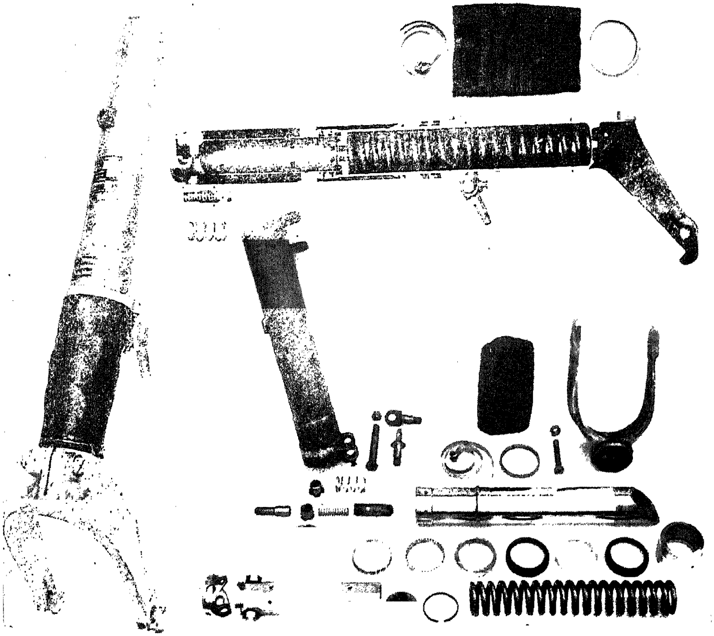
2. *Control Rod Operating Elevator Tabs* (*Fig.* 200).—In this case the component was a solid-drawn tube, 50 mm. dia., with a reduced end portion welded on to it. The extreme end of the latter carried a double ball bearing, and the tube also carried a bolt and nut just below the welded portion. The whole surface was painted grey.

3. *Flap Control Tube* (*Me* 109) (*Figs.* 201 *and* 202).—The flap control consisted of a thin seamless tube at one end of which a brass shank was fitted, and held with six rivets. A hollow steel shackle and screw operated within the shank on a double-start left-hand acme thread. The outer surface of the tube and exposed surface of the shank were coated with a light-green paint.

4. *Flap Control Tube* (*Ju* 88) (*Fig.* 203).—This consisted of a 35 mm. dia. tube with 1 mm. thick walls, to one end of which had been welded a closed end-piece with an internal screw thread. The screwed end-piece carried a light-alloy tube held in place by a screwed washer, which also fitted on the screwed end of the light alloy tube.

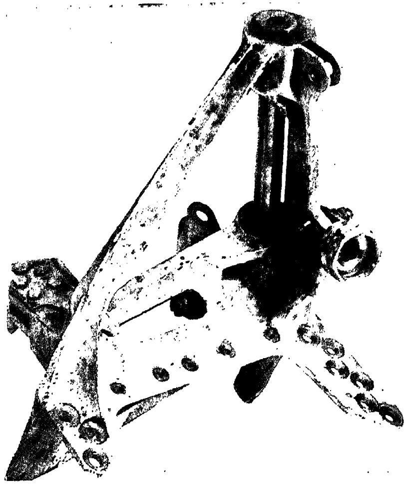
5. *Control Rod* (*Fig.* 204).—The control rod was a built-up construction consisting of two 20 mm. dia. tubes with external splines at one end and internal splines at the other. The two tubes were joined together by a plug round which was held in position a lever arm, the end of which carried a ball bearing.

6. *Auxiliary Control Column* (*Figs* 205 *and* 206).—This consisted of a thin-walled tube bent at right angles at a position approximately one-third of its length. Inserted and held by two screws to the longer section of the tube



Figs. 194, 195 and 196.—Tail wheel for Me 109, showing details, sectional structure, and complete assembly.

was a rubber-covered handle. Riveted to the shorter arm of the tube was a light alloy casing on to which a cap was screwed. The casing had an internal spline towards one end and a small nut and bolt attached to the wall of the casing, acting probably as a stop. Turning on a left-hand acme thread within the cap was a hollow steel cone and shaft, carrying a spring, a light alloy washer and ball race, ball bearings, and attached on the outer side of the cap to a light alloy knob by a taper pin.



Figs. 197 and 198. Undercarriage bracket

The whole of the outer surface was painted dark green with a light-green undercoating.

7. *Part of Steel Tube Operating Diving Brake* (*Fig.* 207).—This part was merely a tube with two light alloy flanges riveted on at one end. The tube was painted green all over.

8. *Tail-plane Incidence Adjustment Crank* (*Fig.* 208 *and* 209).—The component consisted of a steel tube to which was welded a hollow V-shaped strut and a number of flanges (43 separate pieces of tube and sheet were thus welded together), and two links of non-ferrous metal attached to the flanges by pins.

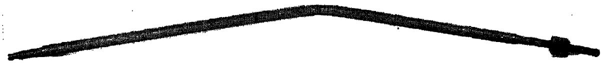


Fig. 199.—Main lead from control column—Me 110.

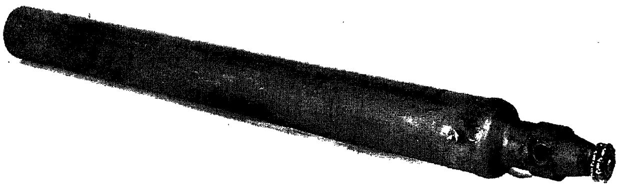
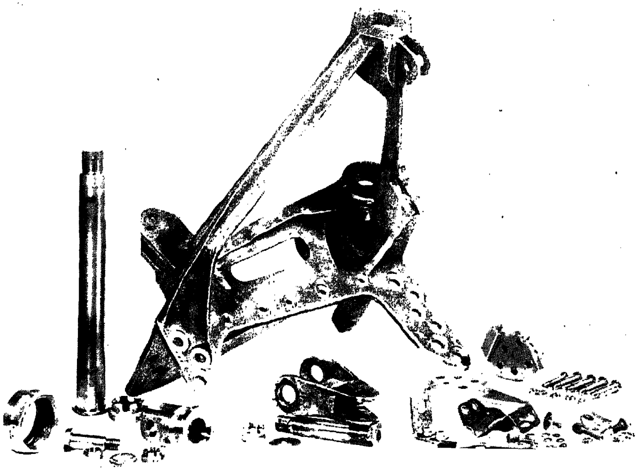


Fig. 200.—Control rod operating elevator tabs—Me 110.



assembled, and showing detailed construction—Me 109.

Report No.	Type of Aircraft.	Component.	C.	Si.	Mn.	S	P.	Ni.	Cr
55	Me 110	Main Lead from Control Column (Tube).							
		Tube	0·21	0·09	0·51	0·005	0·013	0·019	1·06
		Screwed insert......	0·28	0·23	0·57	0·004	0·021	0·11	1·05
		Plain insert	0·29	0·30	0·63	—	—	<0·02	1·05
		Control Rod Operating ElevatorTabs (Tube)							
		Tube	0·26	0·32	0·51	0·004	0·007	<0·02	1·01
		Closed end	0·27	0·28	0·64	0·007	0·009	<0·02	0·98
		Ball-race—							
		Bearing..........	1·14	0·21	0·40	—	—	0·20	1·33
		Bearing balls	1·03	0·34	0·27	—	—	<0·10	0·53
70	Me 109	Flap Control Tube.							
		Tube	0 29	0·135	0·54	0·014	0·029	Nil	0·98
		Shackle and screw..	0·29	0·295	0·64	0·018	0·014	0·08	1·07
113	Ju 88 (4 DME)	Flap Control .Tube.							
		Tube	0·22	0·31	0·44	0·009	0·012	0·12	1·06
		Closed-in end	0·34	0·39	0·79	—	—	0·15	1·00
		Weld metal........	—	0·4	0·48	—	—	0·29	1·13
107	Ju 88 (V. 4GS)	Control Rod (Tube) ..	0·25	0·26	0·51	0·009	0·009	0·05	1·18
105	Ju 88 (V. 4GS)	Auxiliary Control Column.							
		Pt. 1—Tube........	0·255	0·41	0·68	0·010	0·012	0 09	1·04
		Pt. 3—Cone & shaft	0·25	—	—	—	—	—	1·15
		Pt. 4—Spring	0·83	—	—	—	—	—	—
		Ball-bearings	0·42	—	—	—	—	—	13·40
108	Ju 88 (V. 4GS)	Tube Operating Diving Brake.							
		Tube	0·28	0·28	0·65	0·011	0·011	0·12	0·92
108	Ju 88 (V. 4GS)	Tail-plane Incidence Adjustment Cranks							
		Welded assembly ...	0·23/ 0·27	0·22/ 0·31	0·48/ 0·74	0·006/ 0·011	0·007/ 0·015	Trace/ 0·34	0·69/ 1·20
		Large pin..........	0·26	0·30	0·58	0·014	0·010	0·10	1·17
		Small pin..........	0·29	0·30	0·42	0·009	0 009	1·95	1·96
		Eyebolt............	0·25	0·32	0·53	—	—	0·10	1·20
		Ball-race—							
		Outer............	1·02	0·32	0·27	—	—	Trace	1·25
		Inner............	1·03	0·37	0·28	—	—	Trace	0·88
		Balls	1·00	0·28	0·30	—	—	Trace	0·63
		Cage	—	0·14	0·26	—	—	0·02	0·05
		Swivel bushes	0·26	0·30	0·58	0·006	0·010	0·06	1·08
		Miscellaneous nuts ..	0·38/ 0·40	0·19/ 0·35	0·49/ 0·79	—	—	Trace/ 0·10	0·02/ 0·22
71	Me 109	Rudder Control Wire..	0·47	0·17	0·62	0·015	0·012	Trace	0·02
109	Ju 88 (V. 4GS)	Spring (inside bomb-door control tube)	0·82	0·14	0·60	0·021	0·006	0·08	0·07

Mo.	V.	Cu.	Inherent Grain Size.	YP.	MS.	E. %.	R.A. %.	Hardness.	Special Remarks.
0·18	Nil	0·06	4 to 5	40·1	45·7	27·5	—	202/212 B.H.	
0·15	Nil	0·11	5 to 6 (bar No. 4)	37·0	46·5	31	73·5	225	
0·16	Nil	0·10	—	—	—	—	—	220	
0·16	Nil	0·13	5 to 6 (some No. 4)	39·1	44·4	26·5	—	223/235	
0·18	Nil	0·08	5 to 7	—	—	—	—	217/228	
Nil	Nil	—	—	—	—	—	—	810/823 D.H.	
Nil	Nil	—	—	—	—	—	—	890/905 D.H.	
0·25	Nil	—	2 to 4 (mainly 3)	—	69·1	14·0	—	339 D.H.	
0·17	Nil	—	4 to 7 (mainly 5 to 6)	—	—	—	—	309 D.H.	
0·16	Nil	0·13	1 to 5 (mainly 1 to 3)	57·3	61·7	13·5	—	304/310	H. and T. after welding
0·19	Nil	0·16	4 to 6	—	—	—	—	327/331	
0·15	Nil	—	5 to 6	—	—	—	—	—	
0·19	Nil	0·05	5 to 6 (a few No. 4 grains)	41·5	46·0	27·5	—	211/213	
0·17	Trace	0·10	4 to 6 (mainly 5)	—	66·0	22·7	—	342/359 D.H.	
0·20	—	—	2 to 5 (mainly 3 to 4)	—	—	—	—	288/298 D.H.	
—	—	—	4 to 6 (a little grade 1)	—	—	—	—	547 D.H.	Patented and drawn
—	—	—		—	—	—	—	602 D.H.	
0·21	Nil	0·24	—	—	—	—	—	207 B.H.	Cold-drawn and probably tempered
0·17/0·25	Nil	0·09/0·19	—	—	—	—	—	202/241 B.H.	Normalised after welding
0·23	Nil	0·13	—	—	—	—	—	311 B.H.	H. and T.
0·30	Nil	0·07	—	—	—	—	—	340 B.H.	H. and T.
0·22	Nil	0·15	—	—	—	—	—	320 B.H.	H. and T.
Trace	Nil	0·09	—	—	—	—	—	890 D.H.	
Trace	Nil	0·12	—	—	—	—	—	890 D.H.	
Trace	Nil	0·18	—	—	—	—	—	856 D.H.	
Nil	Nil	0·21	—	—	—	—	—	121/118 B.H.	
0·25	Nil	0·11	—	—	—	—	—	293/311	H. and T.
Trace 0·03	Nil	0·04/0·20	—	—	—	—	—	207/255	
Nil	—	—	1 to 4 (mainly 3)	75·0 (0·1% P.S.)	91·5	16·0	60·5	390/412 D.H.	
Trace	Nil	0·12	1 to 6	—	—	—	—	419/469 D.H.	Patented and drawn

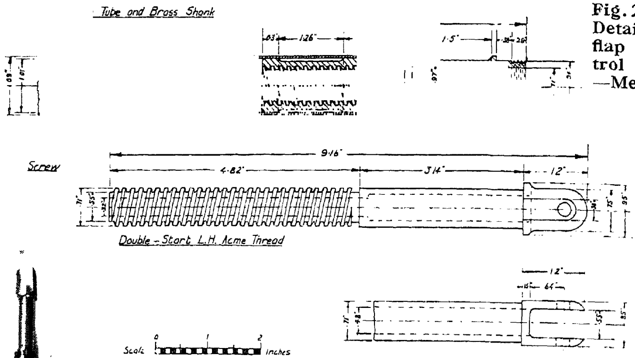


Fig. 202.—Details of flap control tube—Me 109.

Fig. 201.—Flap control tube—Me 109.

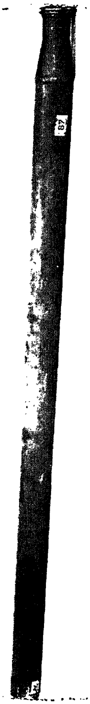


Fig. 203.—Flap control tube—Ju 88.

Fig. 204.—Control rod—Ju 88.

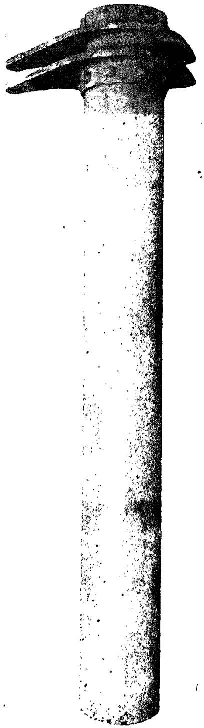


Fig. 207. Part of steel tube operating diving brake Ju 88.

Figs. 205 and 206. Auxiliary control column for Ju 88 assembled and in detail.

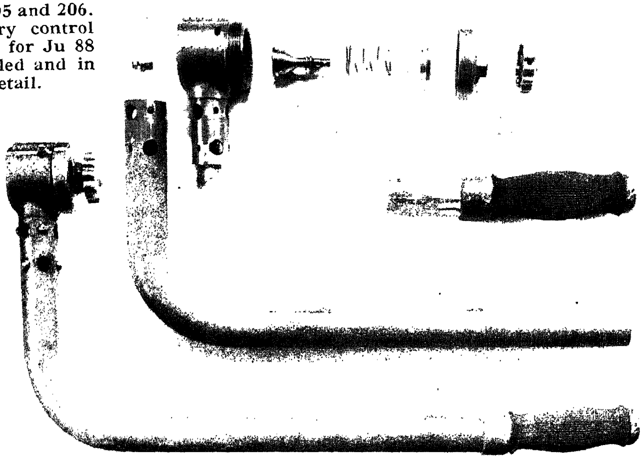
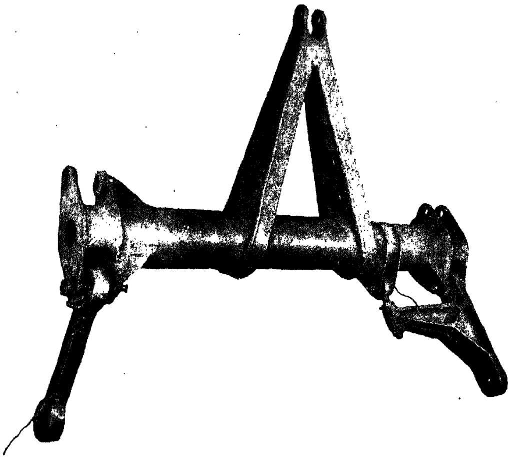


Fig. 208.—Tail plane incidence adjustment crank - Ju 88.



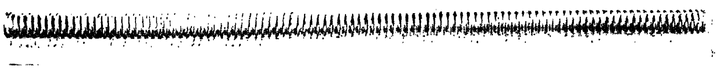


Fig. 210.—Spring—inside bomb door central tube—Ju 88.

on which they were free to move. This was also painted green inside and out.

A general consideration of the results of the various metallurgical examinations are detailed below :—

Heat-Treatment

Hardening and tempering treatments were carried out in the majority of cases. Where welding was used (Reports Nos. 108 and 113), heat-treatment appeared to have been carried out subsequent to welding.

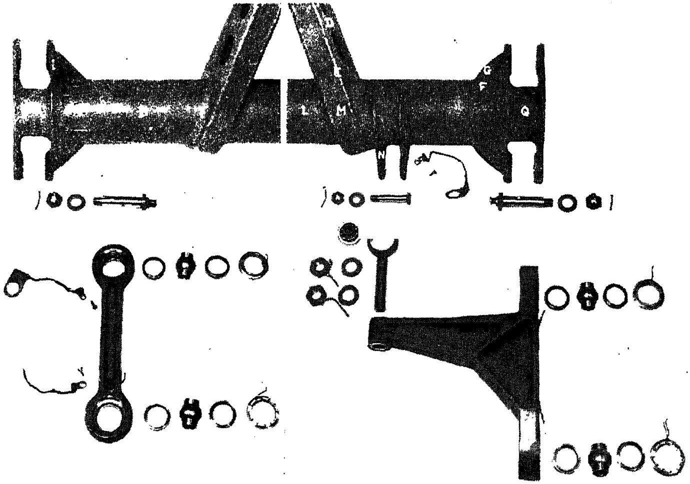


Fig. 209.—Details of tail plane incidence adjustment crank—Ju 88.

(*a*)—Tubular Components

Composition

All the material considered fell into the 1% chromium-molybdenum category, including the weld metal (Report No. 113).

Method of Manufacture

In all cases the steel was probably of basic electric-arc manufacture, and all components were made from hot-worked products. In the case of the tubular parts, these were made from solid-drawn tubes followed by heat-treatment.

Cleanness

In all cases the steel was fairly clean.

(*b*)—Wires and Springs, Ball Bearings, etc.

The springs and wire were all made from carbon steel, patented and drawn, of basic electric-arc manufacture, although that detailed in Report No. 109 may have been of Swedish O.H. manufacture. The ball bearings of Reports Nos. 55 and 108 were made from the usual carbon-chromium steel, but those classified under Report No. 105 were rather exceptional, being 13·5% chromium with 0·4% carbon.

The quality was good in these instances, and in the majority of the minor parts.

Section XIV.—Miscellaneous Parts

In this section a number of miscellaneous components which were examined together are considered individually.

A.—Inner Pipe, Inlet Heater from Exhaust System of Heinkel 111H Aircraft (Report No. 10)

The pipe had been removed from inside the exhaust pipe of the Jumo 211A engine, installed in a Heinkel 111H aircraft. Air for cabin heating was drawn through the pipe. The pipe was $2\frac{3}{4}$ in. o./d., and had been made by bending sheet 0·060 in. to 0·062 in. thick and gas-welding along a longitudinal seam.

The steel was of the following chemical composition :—

	%		%
Carbon	0·13	Chromium	18·07
Silicon..........	0·68	Molybdenum	0·25
Manganese	0·38	Copper..........	0·17
Nickel..........	8·86	Titanium........	0·62

It will be noted that the material was a titanium bearing 18/8 chromium-nickel-austenitic steel containing small and possibly accidental additions of molybdenum and copper. The weld metal was not fully resistant to intercrystalline corrosion when subjected to the standard acid-copper-sulphate test.

B.—Control Chains from Heinkel 111A (Aircraft Report No. 11)

Samples of 8 mm. and 0·500 in. pitch chain were examined. They were found to be commercial products, the smaller one being of the type used for general industrial purposes, and the larger principally for motor-cycle transmission. The chains were of normal design, except that the 0·500-in. chain had plain unshouldered bearing pins and no provision for locking the bushes.

As regards the materials, the departures from British practice were found as given in the table below.

C. — Gun Mounting Parts from Messerschmitt Me 110 (Report No. 52)

The parts examined consisted of: (1) Port machine-gun tube, (2) forward gun mounting, and (3) rear gun mounting.

1. *Port Machine Gun Tube.*—This consisted of a steel tube approximately 65 mm. o./d. and 62·5 mm. i./d., carrying a welded flange riveted at an angle of about 20° to an aluminium alloy sheet, which formed part of the covering on the nose of the aircraft (Fig. 211).

8 MM. CHAIN.

	German.	British.
Bearing pin	C.H. 3% Ni, 0·7% Cr steel..................	C.H. mild steel.
Bush	C.H. 1·5% Ni steel..........................	C.H. mild steel.
Roller......	C.H. 2·5% Ni, 0·2% Mn steel	C.H. mild steel.
Plates......	H. and T. 0·5% C, 1·0% Si, 0·5% Mn steel..	H. and T. 0·65% C steel.

0·500 IN. CHAIN.

Part.	German.	British.
Bearing pin	C.H. 3% Ni, 0·7% Cr steel..................	C.H. 2% Ni steel.
	C.H. 1·5% Ni steel..........................	C.H. mild steel.
Roller.............	C.H. 2·5% Ni, 0·2% Mn steel	C.H. mild steel.
Plates.............	H. and T. 0·57% C, 1·3% Si, 0·45% Mn steel	C.R. 0·75% C steel.

ide use of alloy steels is surprising. ' weight per foot of the 8 mm. chain was slightly greater than that
responding British product, but the 500 in. chain was about 56% heavier.

2. *Forward Gun Mounting.*—The steel employed for both parts was of the 0·25% carbon, 1% chromium, ¼% molybdenum type. The parts had been built up by gas welding in sheet and tube, and none of them had been heat-treated after welding (Fig. 212).

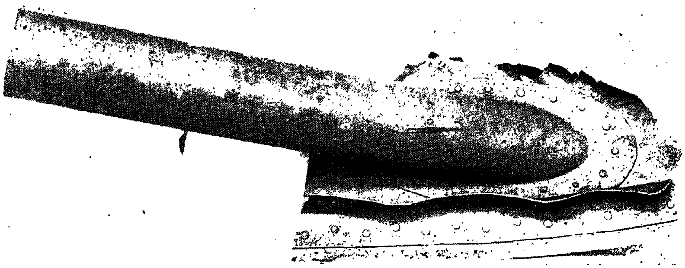


Fig. 211.—Port machine-gun tube—Me 110.

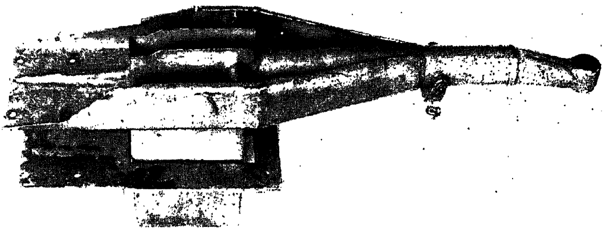


Fig. 212.—Forward gun mounting—Me 110.

3. *Rear Gun Mounting.*—The mounting is shown in Fig 213, after removal of the cap, whilst Fig. 214 shows the approximate assembly of the component parts. The steel used for the main parts was found to be of the 1% chromium, ¼% molybdenum type in either the softened or hardened and tempered condition. A considerable amount of welding had been done on the softened parts, but none of the welds appeared to have been subsequently heat-treated. The chromium-molybdenum steel had evidently been made by the basic electric process, whilst the remaining steel parts were in plain carbon steel of open-hearth manufacture.

D.—German Bomb Release (Report No. 31) and Bomb Hooks (Report No. 32)

A view of the complete apparatus, which was of the electric-magnetic type, is shown in Figs. 215 and 216.

Fig. 217 shows the loaded position. The passage of current through the solenoid caused a clockwise movement of the brass trigger T, which depressed

the arm A of the lever pivoted at B. The resulting upward movement of the other end of the lever which carried a small roller released the prong P. On release this prong moved forward and this movement was transmitted through levers to the bomb hook H, which, by assuming a more vertical position released the bomb.

Hardness tests, chemical analyses, and microscopical examination revealed no unusual metallurgical feature. All the steels were of the plain carbon type, and probably of open-hearth manufacture. The hook was a drop stamping in 0·45% carbon steel in the "as forged" condition.

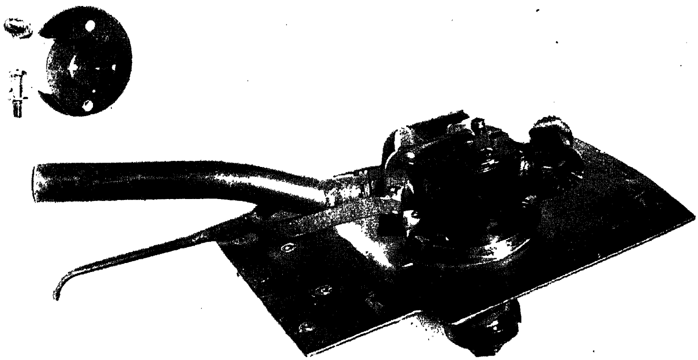


Fig. 213.– Rear gun mounting—Me 110.

Only the bolt, about which the hook pivoted, was hardened and tempered.

Bomb Hooks

Two bomb hooks, one from a vertical carrier (250 kilos.) and one from a light series carrier (up to 50 kilos.) were examined.

The larger hook had been made from air-hardening nickel-chrome steel, probably blanked from plate and hardened and tempered to a tensile strength of about 88 tons per sq. in. The smaller hook had been made as a drop forging in 0·5% carbon steel and left in the "as-forged" condition.

E.—Cartridge Release Mine-layer (Report No. 33)

The component consisted of a light alloy housing containing a toggle arrangement designed to open and close the jaws. Fig. 218 gives a view of the bottom end, while Fig. 219 shows the working parts removed from the housing.

In the closed position the upper toggle levers E and F are practically in line, the tension spring J forcing the arms upward, which closes the jaws G and H. When the trigger C is pressed the cam B fixed to the trigger shaft is moved downwards and the spring pulls the top portions of the jaws inwards, thereby opening the jaws.

The housing was an aluminium alloy casting of very poor quality containing 4·63% of magnesium and 0·86% of silicon.

The parts have been lettered as follows:—

A. Tubular bearings.
B. Cam operated by trigger.
C. Trigger.
D. Nut at end of trigger shaft.
E. Lever arm I.
F. Lever arm II.
G. Jaw I.
H. Jaw II.
I. Cam spring.
J. Toggle lever spring.
K. Four pins.
L. Small pin.
M. Roller at end of cam.

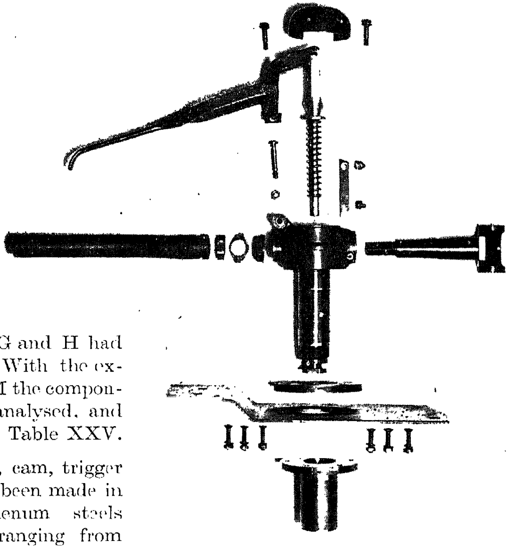


Fig. 214.—Details of rear gun mounting–Me 110.

Parts A, B, C, E, F, G and H had been cadmium-plated. With the exception of parts L and M the components were chemically analysed, and the results are shown in Table XXV.

The tubular bearings, cam, trigger and lever arms had all been made in 1% chromium-molybdenum steels with carbon contents ranging from 0·29% to 0·42%. The jaws were of air-hardening nickel-chromium steel.

Microscopic examination of sections revealed that with the exceptions of the lever arms and trigger nut all the main

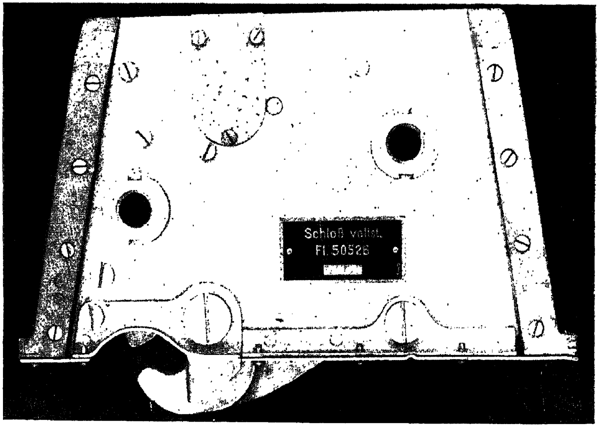


Fig. 215.—Bomb release apparatus of the electric-magnetic type.

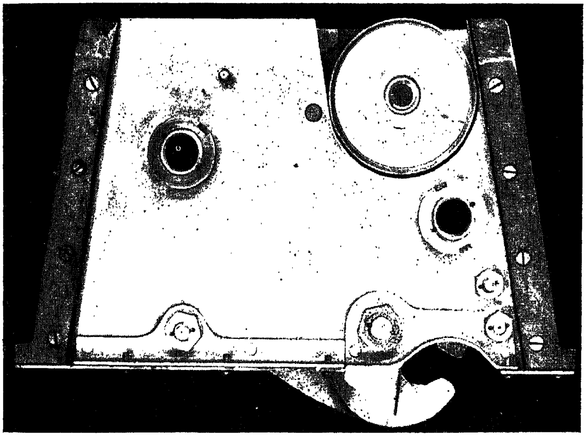


Fig. 216.—The reverse view of the bomb-release apparatus.

steel working parts had been made from high-quality basic electric steel, with the exception of the lever arms which were probably made from Siemens' steel, and the trigger nut of free-cutting steel.

The two springs were made of plain carbon steel of high quality, and all the main parts had been hardened and tempered to hardness values in the region of 300 to 400. An unusual feature observed during the hardness tests was that the hardness of the parts was appreciably higher at the surfaces than in the cores; possibly this was due to the parts having been heated in a cyanide bath prior to hardening. No marked carburised zone was found.

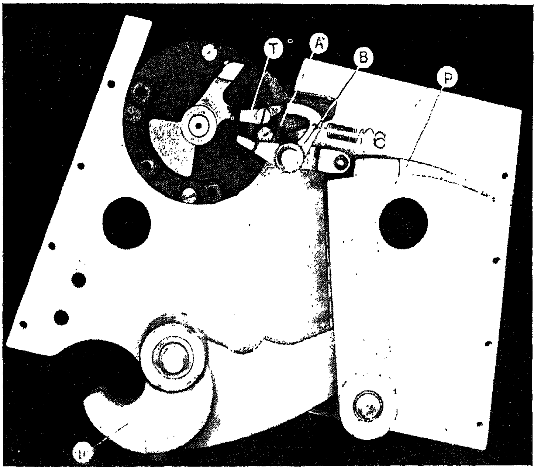


Fig. 217. Showing the bomb release mechanism in the loaded position.

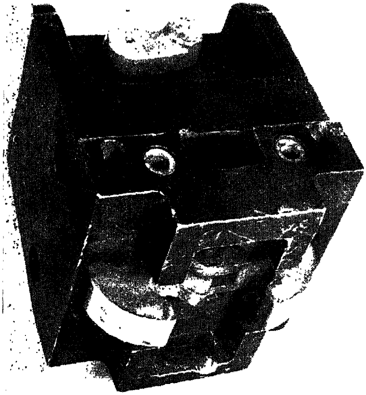


Fig. 218.—Bottom end of a cartridge release mine-layer.

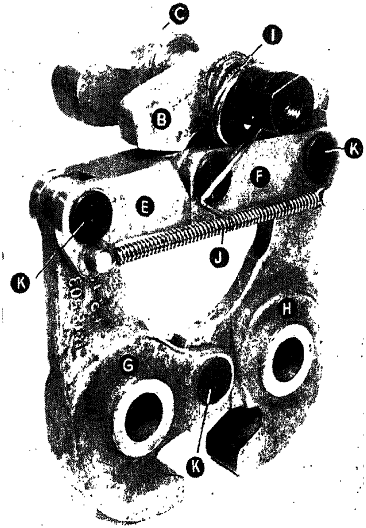


Fig. 219.—Showing the working parts of the cartridge-release mine-layer.

Tensile tests on the lever arms gave tensile strength values of 80 and 85 tons/sq. in. with $12\frac{1}{2}\%$ elongation on $4\sqrt{A}$. The tensile strength of the jaws was nearly 90 tons per sq. in. with 17% elongation on $4\sqrt{A}$.

The cam trigger lever arms and jaws had all been made as drop forgings.

F.—Assisted Take-off Hook from Heinkel 111 (Report No. 34)

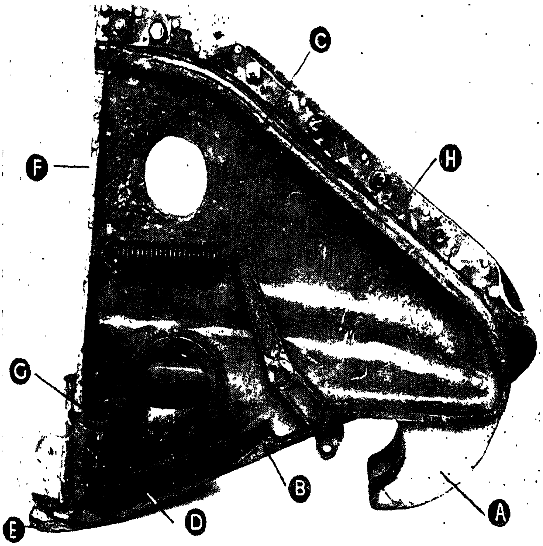
The hook as received is shown in Fig. 220.

The main body of the assembly consisted of a triangular casting (see also Section X—Castings) with two parallel hooks (A) on the front of the underneath face (B); top (C), bottom (D) and back (E) flanges, rear plate (F), and stiffener (G), and a top rib (H). The swivel pin fitted through the lower broader section of the casting and was held in position at each end by a large

TABLE XXV. OF COMPONENTS IN THE CARTRIDGE RELEASE MINE-LAYER.

	A. Tubul. Bearing	B. Cam.	C Trigger.	D. Nut.	E. Lever Arm I.	F. Leve Arm II.	G. Jaw I.	H. Jaw II.		Lever Spring	K. Pin.
Carbon									0·82		
Silicon						·35			0·10		·44
Manganese..........		62				·65			0		40
Sulphur	012	009			·026	·024					006
Phosphorus	012	016			·028	·027					
Nickel	014	013			< ·02	<0·02			<0·	<0·	
Chromium	07	02	15		1·03	1·03			0·	0·	
Molybdenum........	12	22	24	Nil	0·23	·20			N	Nil	0·61
Copper............	10	15	·13		0·11	·12		0·18	—		0·20
Vanadium	Nil	Nil	Nil		Nil	Nil	Nil	Nil	Nil		
Oxygen			0·0026		·0013	018	·0027	0026			
Hydrogen		0011	0·00005		·00012	00012	0·00008	00008			
Nitrogen		·0122	0·0110		·0073	035	·0107	0090			

Fig. 220.—
Assisted take-off
hook—He 111.



nut and retainer clip. The levers were pivoted at each side of the casting, on a thin pin which fitted through the lower broad section of the web at a central position. One end of each lever passed through slots in the bottom flange and the other end was held by tension springs attached to eye-bolts on the rear plate of the casting. Along the top rib, bottom of the rear plate, and the back flanges were remnants of the non-ferrous material of the fuselage, to which the assembly had been bolted.

The main body of the hook was a steel casting in 0·26% carbon, 1% chromium, and 0·25% molybdenum steel, manufactured in the basic electric-arc furnace. The casting was generally sound, and its surface was fairly good. Some building up with weld metal had been done, and filler rod of a similar chemical composition but of somewhat higher chromium content had been employed. The casting was in the normalised condition, and a tensile test gave a maximum stress value of 59 tons per sq. in., with 18% elongation on $4\sqrt{A}$. Izod impact tests gave values ranging from 28 to 35 ft.-lb.

The swivel pin and levers (the latter were drop forgings) had also been made in 1% chromium-molybdenum steel of basic electric-arc quality. The swivel pin was in the normalised condition and in the tensile test gave 56·5 tons maximum stress with 25% elongation on $4\sqrt{A}$. The levers had been hardened and tempered, and a tensile test gave a value of 68 tons per sq. in. for ultimate stress, with 23% elongation on $4\sqrt{A}$.

The lever pin and the springs were in open-hearth quality plain carbon steel. The springs were in the "hard-drawn" condition and had a diamond pyramid hardness of 505.

INDEX.

AIRFRAME COMPONENTS.

ENGINES.

ENGINES.—*continued.*

ENGINE DETAILS

ENGINE DETAILS.—*continued.*